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THE BRITANNIA TUBULAR BRIDGE OVER THE MENAI STRAITS, 1851

# CIVIL ENGINEERING

BY

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WITH FIFTEEN ILLUSTRATIONS

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# PREFACE

IT is hoped that this volume will take its place among others in a series of books on business, and therefore it is not written in the technical language of a scientific treatise. It is designed rather for the use of busy men, and for the information of the casual reader who may happen to take any sort of interest in engineering—for this is a subject of many-sided interest.

It seemed necessary at the outset to consider what engineering really is; and its true character is discussed in the first chapter along with the records of its origin in this country as a civil profession.

Its progress is very briefly sketched in the first three chapters, and the incidents here recorded have been taken mainly from such historic sources as are open to all men, while a few have been given from the Author's own recollections and experiences.

In the writing of the next three chapters the

object has been to describe the ordinary occupations of a civil engineer—what he finds to do in the field, or the drawing-office, or a Parliamentary Committee-room—and to say something about his professional duties in the various positions that he may be called upon to fill: all of which, it is hoped, may be useful to the student who is preparing to enter the profession, and may also be of some interest to the educationist.

The seventh chapter speaks of the intimate relations between science and engineering. And here, perhaps, an apology is due for attempting to discuss some matters of elementary science in the plain language of business. But almost everyone is now a user of power, and business men are all more or less interested in the conservation of energy. The language seemed to fit the subject well enough, and it sacrifices nothing on the score of accuracy.

The very difficult subject of education is discussed at some length in the next chapter. Some of the necessary subjects of study in the education of an engineer had just before been indicated, when the practical uses of science in engineering were considered in chapter vii.; but the education of a civil engineer must also have reference to those wider

duties and responsibilities which have been described in the earlier portions of this book.

Chapter ix. contains a few concluding remarks upon the present outlook, as it appears from several points of view—commercial, professional, and educational.

My acknowledgments are due to many authors and eminent engineers—to Macaulay, Birch, and Smiles for the record of many historic facts, while the later papers and works of Sir B. Baker, Mr. J. Mansergh, Sir W. White, Sir E. Leader Williams, Sir Douglas Fox, Prof. Kennedy, and many others, have furnished examples of modern engineering.

T. C. F.

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# CIVIL ENGINEERING

## CHAPTER I

### THE ORIGIN OF CIVIL ENGINEERING IN BRITAIN

AMONG the great works of construction whose remains have come down to us from Roman or still earlier times, there are many which we rightly regard as monuments of engineering skill. In such words we commonly speak of them, and we therefore think of engineering as one of the oldest of the arts, distinguishable in some way from the rest, and having its true origin far back in the very beginnings of civilisation.

For the present, however, we shall be chiefly interested in the civil engineer as we have come to know him more lately in our own country; and in this little volume it will be our object to discover, if we can, the true character of his work and its influence upon the world—his position in the industrial life of

our community, and his past or present relations with science, art, law, or business.

In discussing these matters, we need not go back to a remote antiquity in any hope of finding a continuous line of historic development. Engineering had lived many centuries ago, and among other civilised nations; but we have to consider its origin or its renaissance in England at a much later period, and its gradual advance to the place which it now occupies. Many of us, indeed, can easily remember the time when it seemed to stand in a very isolated position among the recognised occupations of English life. It did not fall into line with the old arts, crafts, and trades, nor take its place naturally among the "learned professions," as they had hitherto been known to society.

All these arts, trades, and professions had come down through a long line of descent, retaining many of their mediæval traditions, and they are easily recognised in the familiar characters of historic literature. But engineering as a civil profession could boast of no such ancestry, and we can scarcely find in English literature any trace of its existence until the beginning of the nineteenth century or thereabout.

At some such date the civil engineer seems to have made his appearance as a new-comer amongst the

people of old England, standing very much in need of an introduction to such respectable company. For some years onward people could hardly tell what to make of him or his business—what he proposed to do for an honest living, or why he should be there at all. It was not easy to understand his newly-assumed title, though it might, perhaps, be surmised that an engineer must have something to do with engines—and even to-day it is possible that the minds of some people do not travel much farther than this in trying to imagine what can be the occupations of an engineer.

It is to be remembered, however, that the word "engineer" (without the prefix) had for many centuries been connected with certain military operations, and the records of ancient warfare give us some early indications of the man, his methods, and his work. Certainly he had something to do with engines, and they were engines of war. Long ago he had made the battering-rams and the catapults that were used by Roman generals for the attack upon fortified cities; and he had devised the boat-bridges for the crossing of wide rivers by their invading armies.

Already we can gather that he was always a man of some original resource, setting about things in his own way and in a certain deliberate fashion. The gallantry of the Roman soldier was good enough for

anything, but it was powerless to effect a breach in massive stone walls, and the engineer would not be likely to have much faith in a blind waste of energy. Recognising the nature of the task that lay before him, he set himself quietly to study the adaptation of more suitable means to the end, and he knew that when his engines were made ready they would effect more in a week than the Roman soldiers could accomplish in many months.

Again, at a much later date we find him in this country devising artillery of another sort, casting guns of brass and of iron in the time of Queen Elizabeth—to say nothing of the leather guns which are said to have been used in the siege of Donnington Castle.

Or, again, we meet with him as the engineer-officer laying out lines of fortification—planning bastion and fosse and casemate.

In mediæval times the military engineer can always be distinguished from the armourer—a man of wonderful skill in the twisting of chain-mail and the tempering of sword-blades. This clever artisan must have possessed technical knowledge of a high order, but his methods were always those which he had learned in his apprenticeship, and his weapons were made to a standard pattern. It was not in that way that the engineer could hope to attain his object.

Every new work, whether planned for attack or defence, would be certain to present a new problem. He must study the local features and all the new conditions of the problem on the spot; and in each case he must select or devise the special means that were best suited to the attainment of his end. If a well-tried plan seemed to be the best, he would adopt it, and if not he must throw it aside and boldly try to devise a better one. Thus we find that his designs were often undergoing change and improvement—he could not be content with smooth-bore guns when he had found the way to make better ones, with a longer range, a lower trajectory, and a greater muzzle-velocity.

But all through the Middle Ages this man's invaluable faculties of mind had seldom been directed to anything better than the destructive operations of war, and his triumphs were short-lived. Of course his inventions were soon taken up by the enemy and turned against himself, and it was inevitable that he should presently find himself "hoist with his own petard."

When Shakespeare wrote these words he was surely giving us a warning that would apply through all time to the warfare of Man with Man.

But victories of a more lasting kind had already been won, when men had joined in waging against

Nature that beneficent warfare which is the appointed lot of humanity upon this earth.

The splendid bridges, roads, and aqueducts built by the Roman emperors, and at least some of their harbours, had remained through the centuries as a permanent conquest for humanity, and a permanent addition to the real wealth of the people all over the Empire. And it was in such works of construction that the engineer had received his best training. Here his skill had been matched against the great forces of Nature, and he had learned to avoid the mistake of underrating his adversaries. He could never reckon upon finding them asleep, and they often delivered an attack in some unexpected direction—collapsing his arches, undermining his foundations, or sweeping away his breakwaters—unless he had foreseen each line of attack and duly fortified his position. In such encounters he had gained a great deal of experience, and success had given him faith in his resources. Estimating carefully the true magnitude of his difficulties, and studying always the adaptation of means to his end, he had acquired a steady confidence in the calculable results of rational methods.

Coming down to nearly the end of the eighteenth century, we shall better understand the situation if we consider for a moment how such works of con-

struction had hitherto been initiated. In old Rome they had been taken in hand by the State, and in this matter the Roman emperors had apparently followed the example of older civilisations. Thus we learn, from Dr. Birch's translation of the inscription of Una, how docks were built or excavated upon the Nile to facilitate the transport of stone for certain pyramids in Egypt, and apparently to get over the difficulty of loading or unloading the barges at times of low water in the river. The inscription was written by the "superintendent of the docks" (probably the chief engineer), and he is careful to tell us, again and again, that in building them he did everything under the commands of his divine majesty, the King Merenra —a king of the Sixth Dynasty.

Now the men who had carried out these works of construction could not properly be called civil engineers: they were Government officers acting on behalf of Pharaoh or emperor or Pontifex Maximus.[1]

At the same time we should remember that, in our own country, Government had hitherto done very little in that way, and the country was in what we should now call a deplorable condition. For the English Government, more than any other in Western

[1] The title of Chief Bridge-builder belonged to the Roman emperors before it was used by the Popes. Its significance is somewhat doubtful.

Europe, had followed the plan of leaving its subjects to mind their own business. And perhaps the Government was right—it *was*, indeed, the business of the people.

The new title, therefore, or the old title with a new prefix, placed engineering in the new position of a civil profession; but it had also another meaning. The profession set before itself a new aim and object which had not been contemplated by the military engineer: it had come to do something for the needs of a civil community — to build up and not to destroy.

If it began to exist as a recognised profession at some time near the end of the eighteenth century, it celebrated its coming of age exactly in the year 1828 A.D., when the Institution of Civil Engineers was founded under the Royal Charter of King George IV.

On this important occasion it was necessary to define in precise terms what civil engineering was or intended to be, to explain its position among men and the nature of its programme; and all this is now duly set forth in the terms of the Royal Charter, and proclaimed to all whom it may concern.

The Charter declares that the institution is founded to promote the acquisition of a particular species of knowledge, so that the institution itself is obviously

a scientific one. But the civil engineer does not exist merely for the acquisition of knowledge, nor only for its extension and diffusion: he has something else to do in the world, and his functions are defined in the notable words which immediately follow in the Charter—they are to "*Adapt, Convert, and Apply the Great Sources of Power in Nature to the Use and Convenience of Man.*"

In these remarkable terms, framed probably by Thomas Telford, who was the first President of the institution, the civil engineers issued their prospectus to the world. We must presently consider how far the programme has been carried out, but just now we should look at the prospectus itself. In the first place we cannot help observing that it has very little to say about engines or machinery; and the omission is all the more remarkable because many people have entertained a certain implicit belief in the virtues of machinery. Evidently Archimedes must have thought a great deal of his Lever. However, he did not say that it would move the world; what he did say was exactly this: "Give me a fulcrum and I will move the world." He knew very well that the lever was powerless to do anything, and the mighty task was to be wrought by *him*—the man Archimedes, standing not more than six feet in his stockings.

And of course it is the same with all the other

mechanical appliances — the wheel and axle, the pulley, the wedge, the screw, and the rest of them. The old schoolmaster spoke of them as the "mechanical powers," but they were not powers at all—mere bits of shaped metal and wood with no more of life or power in them than any other pieces of dead matter. All that you can properly say of them is that they are just so many tools which you can put into the hands of Roman slave or British freeman; and in either case it is the *man* who will have to do the work, with such poor overtaxed muscular effort as he may be able to bring to the task.

Perhaps the civil engineers have, in some sense, gone nearer to moving the world than Archimedes had done; but our text shows that they did not hope to do it by the mere employment of any such dead mechanism.

Industry could only drag painfully along, so long as it was left to the slow drudgery of manual labour, and the use of mechanical appliances would not help the matter very much. What was wanted was *more power for the work of the world*, and the engineers looked for it in the "great sources of power in Nature."

We may notice in passing that one of these had recently been set to work by James Watt in the

steam engine, and yet our text makes no mention of the steam engine nor of the water-wheel.

But was the steam engine itself only another piece of mechanism—just a tool and nothing more? Certainly nothing else so far as its outward and visible mechanism was concerned, but it differed from the other appliances in one essential particular—the tool was meant for the use of an invisible giant, or it was a tool with the giant behind it. Many people could see and admire the machine and yet fail to catch any glimpse of the invisible worker,[1] but the engineers had measured his capabilities. He was one of their sources of power, and could be reckoned upon to get through more work in a day than would be accomplished by many thousands of slaves driven ever so hardly. The boiler and the engine were only a means of "converting" and "applying" the power of heat, and only one of several possible means (such as the later gas engine). Our programme, therefore, mentions the conversion and application of this source of power without speaking of subsidiary mechanism.

Let us consider next the ultimate objects which are kept in view in this programme. The Roman emperors had catered liberally for the pleasures and

[1] Even John Stuart Mill speaks of the steam engine as a "tool," and apparently as a tool for the use of man.

luxuries of the Roman citizen; but the "Use and Convenience of Man" are words of quite different meaning. They suggest that the aim of these men was rather to meet the actual requirements of every-day life, not in the amphitheatre, but in quiet English homes—to alleviate the wearing toil of humanity and add something to its comforts. For all such purposes the definition is as comprehensive as it can be. It is more than wide enough to cover all the material needs of life, for it would embrace all such arts as printing, and includes, indeed, everything that *can* be done for mankind by *such agencies* as are specified in the programme—the sources of power in Nature.

And if you only have the *power* at your command you can accomplish much. Give it fingers and it will do for you almost anything that you can ask—it will hew the wood and draw the water, or it will turn the spinning-wheel and weave the cloth, or it will plough the fields and reap the crop and carry the grain to market. If it could render such services they would be enough to revolutionise the old conditions of life, and the engineers seemed to think that it could do all this and a great deal more.

When such proposals were first put into concrete form it was inevitable that people should look at them with mistrust, regarding them as visionary

THE CITY OF DUBLIN STEAMSHIP CO.'S MAIL PACKET "CONNAUGHT"

schemes; but in truth the prospectus is a remarkably sober one, for the means were certainly adequate to the end, and it could only be a question of intelligent and successful adaptation. If the sources of power could only be put into harness there was very little more to be done.

The part which is allotted to the civil engineer in this programme is, therefore, a subsidiary one, and it is described in terms that will give us a good insight into the true character of engineering. His function is to "*Adapt, Convert, and Apply*" the great sources of power in Nature to the use and convenience of man.

We notice at once that he does not here appear in the character of a wonder-worker. His purposes are to be attained in a perfectly natural way—there is no magic about them. He does not profess to "call spirits from the vasty deep," but declares plainly that his sources of power are to be found *in Nature*.

It follows, of course, that he does not pretend to *create energy*, nor indulge in dreams of upsetting the physical order of the universe by his inventions. He finds an abundant store of energy laid up by Nature in the coal measures, and a perennial source of power in that ever-recurring cycle which brings the rainfall to the rivers and the rivers to the sea, and carries back the vapour to the mountain-tops.

Taking these gifts of Nature, he proposes here to use them for the benefit of man, converting and applying them by such mechanical (or electrical) instruments as he may be able to devise or employ.

The simple wording of the definition, as above quoted, is certainly wide enough to include all those important mechanical inventions which have so greatly moved the world since the eighteenth century, and describes correctly the true essence of every one of them; and this will become more clearly manifest when we come to consider them one after another. It is a little remarkable, however, that the Charter of this body of inventors does not anywhere contain the word invention, and there may be a reason for this omission.

It is already pretty clear that almost every feature in the steam engine is an invention for the "conversion" of heat into mechanical power, and therefore the finding out of all *such* inventions is included as a part of their programme. Perhaps every *useful* invention may be described as the intelligent adaptation of special means to a useful end (as in the language of the Charter). What else, indeed, can it be? But we have seen many "inventions" of another sort—some that have had no useful end, and others that have sought to attain their ends without any intelligible means. These are among the vain inven-

tions that have come to nought, and *they* were not to be included.

Or, again, the word, in its popular acceptation, may convey another meaning which these men did not wish, perhaps, to convey. Some people have spoken of "invention" as though it were a kind of magic, taking everybody by surprise—the unexpected advent of some totally new idea from the outside, without any conscious application of rational method on the part of the designer, any clear recognition of the goal, or any purposeful study of ends to be attained and means to be employed. It was certainly *not* by any such process that the separate condenser or the governor was invented by James Watt, or the link motion by Stephenson.

Inventions like these have not been hit upon by chance or by any tentative guess-work; their features show plainly enough that they owe their origin to downright straight thinking with a definite purpose before it. When the inventor was so deeply engrossed in his problem, he was not wandering idly in dreamland, but wide-awake and pressing hard in pursuit of his object by one path or another.

It has happened, however, more than once that something which looks like *accident* has revealed to him an alternative path that might be tried, as it did in the case of the blast-pipe, and the word invention

is sometimes applied to such *incidental discoveries as this*. But they have been exceptional incidents, and the pioneers of engineering could not include them by anticipation in their programme. They could see their great task clearly before them; the work was everywhere waiting to be done, and Nature's gift of power was waiting to be used for the work. In trying their best to apply it, they seem to have entered upon their task in the spirit of the earnest student, who does not expect to get his problems worked out for him by the master, nor to find the answer written up already by accident. The school of humanity would not make progress in that way. But each scholar possessed already those faculties of the human intellect which are themselves only a faint reflection of the master Mind, and which find their most delightful exercise in working at such problems of construction.

It is on such lines that the engineers have worked; and the Charter shows also that they foresaw the details of the task that lay before them. The programme goes on with a provisional list, whose items have now become quite familiar to us, although at the time they were among the things that were still ahead. The sources of power are to be directed "as the means of production and of traffic in states, both for external and internal trade," "as applied in

the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns."

The list was, at all events, quite enough to begin upon; and in the next chapter we may follow their progress as they began to convert and apply the great sources of power in Nature; but first there is one other question to be asked, and it is an important one.

These men could do nothing alone, and their projects must all come to nothing unless they were taken up, either by the State or by some great combination of private individuals such as would furnish the financial means for the execution of the works.

When engineering began as a civil profession it certainly could not hope for much support from the British or any other government—its sole patron in this country must be the British public.

Had these engineers been reckoning without their host? Their proposed work was indeed the business of the people, but could it be expected that the people would take it up? The capitalist generally

sows to reap, and engineering projects are the longest of long farming. The harvest was not to be looked for in a few months, and could never be gathered at all except by a people who had the daring to start upon such work with a patient and strong faith in its ultimate results.

However, British enterprise was not likely to fail at this point. Events have shown that these civil engineers had started their operations in the right country.

## CHAPTER II

### THE PROGRESS OF BRITISH ENGINEERING

WE have lived through so many changes lately that the earlier ones are apt to be forgotten. Of course we remember that there *was* a time when the English people did not ride upon motor-cars, and a still older time when they did not even travel by express trains. Some of us have still a fading remembrance of the old coaching days, and everyone has read the journey of Nicholas Nickleby from London to Yorkshire, but our thoughts do not often go back any farther than that. When the immortal story was written the fast coaches must have been as new as the railways are now; but it tells us nothing about travelling in the days that had gone before, and *those* times have faded into the dim past as completely as the times of Julius Cæsar.

To form any just idea of what has been done by engineering in Britain, we must compare the present condition of the country with what it was in the middle of the eighteenth century, or a few years

later—and down to that time things had remained for many centuries without much alteration. The old Roman roads had been used all through the age of chivalry without improving or extending them very much, for it seems to have been no one's business to think of such matters. But something had certainly been done before the beginning of the nineteenth century to provide better lines of communication. Brindley had been making canals for the Duke of Bridgewater, and the public highways had been improved in some parts of the country.

Down to 1740, or later, the roads were nearly as bad in the great towns as they were in the country. Lord Hervey, who was then living in Kensington, writes that between that village and London "the roads are so bad that we live here in the same solitude as if cast on a rock in the middle of the ocean; and the Londoners tell us that there is between them and us an impassible gulf of mud." And if the description is more picturesque than accurate, we can still detect in it a substratum of truth.

In the streets of London itself it is said that the ruts made it unsafe to travel in wheeled vehicles, and they were not commonly used. When Prince George of Denmark paid a state visit to Petworth, in wet weather, he was six hours in driving over nine miles,

and a number of men had to walk on each side of his coach to keep it upright. Of the carriages which conveyed his retinue several were upset on the journey, and one of the party complained that during fourteen hours he never once alighted except when his coach was overturned.

In country districts the roads are described as forming a narrow hollow way, little wider than a ditch, barely allowing the passage of a waggon drawn by horses in single file. This deeply-worn channel was sometimes flanked by an elevated causeway covered with boulder-stones, along which the local traffic was carried on the backs of single horses.

Facts like these, which stand recorded in Macaulay's *History of England*, are enough to show how every kind of industry was fettered by the difficulties of transport. Coal-mines could hardly be worked unless they were situated within a few miles of some seaport or navigable river, and the total output over the whole kingdom was not more than five or six millions of tons per annum. The cost of road transport by pack-horse was about *2s. 6d.* per ton per mile, enough to prohibit the use of coal entirely in all inland towns at any distance from the coal-pits; and in the same way it was practically impossible to convey any heavy goods to the consumer unless he lived within a few miles of the source of production. Of course, business

was done very slowly, like everything else, for the pack-horse governed the pace, and it would often take weeks or months to get any news of what was going on at another part of the country.

From this helpless, paralysed condition, industry was first rescued by the construction of highways and canals. The muscular energy of men and of horses is one of the natural sources of power, and capable of doing some little work; but as yet it had been struggling under the most unfavourable conditions, and what engineering did for it was to improve the method of its application—to smooth down the obstacles which had called for so much useless expenditure of effort. The low places were filled up and properly drained, the gradients were improved, and the roadway formed of durable material affording a fairly even surface—and now it was possible to get along at a quicker pace. The cost of goods transport was thus reduced from 2*s.* 6*d.* to about 8*d.* per ton per mile, and at the same time the era of the fast coaches began. We read that between London and Edinburgh the coach started regularly once a month from each city, and performed the journey in about ten days during the summer or twelve days in the winter season.[1] Such early triumphs were hailed with much satisfaction by the travelling public. An excellent coach-

[1] The fare was 11½ guineas inside, and 7½ guineas outside.

road had been made from London to Bath, and in 1774 we read that Burke travelled from one city to the other with "incredible speed," doing the journey in twenty-four hours. Altogether about 120,000 miles of roads and highways have been constructed in England, Scotland, and Wales.

From this beginning, however, we find that improvements went forward more rapidly, and the construction of canals was an important help to progress from 1760 to the end of the century. It effected a further reduction in the cost of transport, and promoted the extension of industry in many directions. The canals were mostly worked by horse-traction, and they enabled the horse to drag a very great load at a slow speed. The speed suited the horse well enough, and it kept down the tractive resistance to a very low figure.

To apply the power of draught-horses at a somewhat higher speed, the next engineering improvement was the laying of tramways for mineral traffic. At low speeds the tramway was hardly so efficient and easy a means of transport as the canal; but it had the advantage that it could be worked at a trotting pace without greatly increasing the resistance, and this was impossible in the canal.

The way was now open for the application of steam-power to the work of internal transport, and for the

performance of many other services which we are not just now considering, and at this time the steam engine was almost ready for its work.

The watchmaker at Glasgow had found out what was the matter with the model of Newcomen's old machine sent down to him for repairs. By a series of brilliant inventions, extending from 1769 through many succeeding years, James Watt had succeeded in making the condensing engine a practically useful machine for the conversion of heat into mechanical work. It had already lifted the chains from the men who had been condemned to the pumping of mines, and had come to the help of languid industry in many other places and in different ways.

Watt had always been content to work with steam at low pressure; but in Cornwall Smeaton and Trevithick began to use high pressure, controlling it safely in the Cornish boiler; and it enabled them to dispense with the condenser, the cooling water, and the air-pump. The non-condensing engine was lighter, less bulky, and altogether more portable.

To the minds of Stephenson, Blenkinsopp, Trevithick, and some others, it now seemed to be so portable that it might be put upon wheels and made to drive its own carriage. While others were trying to make it run upon common roads, Stephenson designed it for drawing heavy trains upon lines of tramway and

THE CUNARD COMPANY'S STEAMSHIP "LUCANIA"

in either case such an engine would be superseding the horse.

The prospect of such a change was viewed with much public interest and concern at the time, and especially in racing circles, as appears from the newspaper notices of the period. Thus the *Times* of July 8th, 1808, as quoted in a recent number of the *Engineer*, contains the following:—

"We are credibly informed that there is a steam-engine now preparing to run against any mare, horse, or gelding that may be produced at the next October Meeting at Newmarket: the wagers at present are stated to be £10,000; the engine is the favourite."

This was an engine of Trevithick's, but it is uncertain whether the race ever came off; it is referred to, however, in the *Observer* of July 17th, as follows:—

"The most astonishing machine ever invented is a steam engine with four wheels so constructed that she will with ease, and without any other aid, gallop from 15 to 20 miles an hour on any circle. She weighs 8 tons, and is matched for the next Newmarket Meeting against three horses to run 24 hours, starting the same time. She is now in training on Lady Southampton's Estate adjoining the New Road."

The situation is reviewed in more critical spirit by the *Sun* of July 21st:—

"The new trotting match, in which one of the competitors is to be a *steam-engine*, if the issue should

be favourable to the latter, may be expected to produce a great change in many of our calculations. . . . We shall know what amount of posting there is upon any road, not by the dust, but the smoke; instead of half a peck of oats, a sack of coal will probably be a feed for a stage of moderate distance. A coachman, instead of being praised as a good whip, must be rated by his qualities as a stoker: our four-in-hand clubs will be extinct, and those who are now said to be run out as sportsmen will hereafter be recorded as burnt out!"

But George Stephenson was thinking not so much of the racehorse as the clouds of dust upon the public posting-roads; and in designing the locomotive for general railway traffic, he had looked at the problem all round, providing not only power enough for heavy loads and high speeds, but also a line of way that should offer the smoothest and easiest travelling—easiest for the passenger and easiest for the engine.

Each constituent part of the machine was specially adapted to its purpose—the compact boiler with its great heating surface and forced draught, the engine with its reversing link-motion, and every organic part to its organic function; but beyond all this, the boiler, engine, and carriage were so skilfully adapted to each other that the organism, as a whole, has remained as a permanent type and model down to the present day.

As we see it now, the locomotive bears witness to the adaptive intelligence of Watt, Trevithick, George Stephenson, his son Robert, and a few other men. As the grooms and stable-boys saw it at first, it must have seemed to them and to many other people something like a new creation—and so indeed it was. But if the creation of such things falls within the province of human intelligence, the creative process did not begin in these men by watching the steam from the spout of a kettle, and it was not carried on by the fortuitous advent of any aimless ideas. If we could give credit to such fables, we might almost begin to believe in the spontaneous and purposeless evolution of all things—horses as well as locomotives.[1]

However, the engine was only one part of the problem, and the larger part remained for solution. The railway must be adapted to the locomotive—to its weight, its work, and its intended speed. To lay out any such line, with easy gradients and easy curves, for a long stretch of many miles, over hill and valley and river, was a task that could not be accomplished by one effort of thought. When once the permanent way had been well designed, its pattern

[1] The recent statement of Lord Kelvin as to the clear teaching of science in regard to any theory of a purposeless evolution reminds us that engineers are always vividly conscious of what is involved in the adaptation of means to an end, and the impossibility of adaptation by accident.

might be followed upon many railways, but nothing else would be the same in any two cases. Cuttings and embankments, tunnels, bridges, and viaducts must be skilfully adapted in each case to the natural features of the ground. The task was soon taken in hand by a number of engineers all over the country, and carried out upon a scale which often dwarfed the greatest works of the old Romans. Robert Stephenson had soon bridged the Menai Straits for the passage of the Irish mail, and Brunel had carried his splendid line from London to Bath through the Summering Cutting and the Box Tunnel.

Stephenson had begun with a gauge of 4 ft. 8½ in. between the rails, and it has been adopted almost everywhere; but Brunel laid the Great Western Railway to the "broad gauge" of 7 ft.; and all the way from London to Swindon the line had no gradient steeper than 1 in 300 and no curve sharper than eighty chains radius. This magnificent road was intended for high speed, and the express trains covered the distance at an average speed of sixty miles an hour, maintaining the service with regular punctuality.

Narrow-gauge engines were built upon racing lines to vie with this speed, and when the locomotives were raced against each other a speed of more than 100 miles an hour was recorded upon both lines. The "battle of the gauges," however, was not de-

cided by speed-trials, but rather by commercial considerations. A break of gauge was a great source of inconvenience, and the Great Western was ultimately relaid to conform with the railway systems north and south of it.

In speaking of railway extension, it must not be forgotten that British engineers have received invaluable aid from the constructive skill and business capacity of British contractors; and among the leaders of such enterprise the names of Peto, Brassey, and Betts will certainly be remembered.

Within a period of about fifty years a network of railways had been spread over the United Kingdom, and trunk lines had been constructed in India and the Colonies. But beyond the limits of British dominion long lines of railway were laid out and constructed by British engineers in many European countries. Foreign governments had entered into negotiation with the great English contractors, and the engineering agents of one such firm were exploring, surveying, designing, and building new lines of railway in Denmark, Russia, Germany, Italy, Austria, and Hungary at the same time.

The activity of British enterprise in the work of railway extension reached, perhaps, its high-water mark in the year 1866, when the outbreak of the Prusso-Austrian War was followed by a period of

inaction; but the work was soon resumed both at home and abroad, and in almost every part of the world the railway system has now been carried to the confines of civilisation. Within the limits of the United Kingdom we now have about 22,000 miles of railway, which have been built at a cost of about £990,000,000. The traffic upon these home lines has been continually increasing from the first, and at a rate which is itself increasing from year to year. At the end of the century the annual traffic had reached 425 millions of tons of goods and 1,100 millions of passengers, but it is scarcely possible to realise all that is implied by such figures as these.

George Stephenson is reported to have said, "Let the country make the railways, and the railways will make the country," foreseeing, perhaps, that the railways and the industries they were intended to subserve must inevitably react upon each other in such manner as to rapidly foster the development of both.

We may remember, however, that during the same period mechanical power had been directed in various other ways to the use and convenience of man—that every such application of power has augmented the production of real wealth, and has been followed, not only by an increase of population, but also by an advance in their general standard of living and in

the magnitude of their daily demands. From the Year Book of the London Chamber of Commerce, near the end of the century, we learn that the coal brought into London and actually consumed there amounted to nearly 8 millions of tons per annum. The provisions actually consumed in London are not so easily to be estimated, but they must include at least 30 millions of bushels of wheat, and perhaps 300,000 tons of fresh meat; and it would therefore appear that the people of London could hardly live in comfort unless they received every day a supply of about 25,000 tons of food and fuel. For all such supplies London must depend mainly, and the inland towns almost wholly, upon the transport of goods by railway.

Stopping here for a moment, let us carry our thoughts back to the beginning of this story, when the pack-horse was wending his toilsome way towards London with one or two sacks of grain upon his back, and there was nothing else to be seen upon the road except, perhaps, a waggon standing fast in the mud, while the waggoner was urging his struggling team in vain to drag the wheels out of a rut. Many reflections are suggested by such a glance backward to the time when railways were not. The contrast will illustrate forcibly enough the changes that have been wrought in the conditions of

human life, and the part that has been played by engineering in rendering such changes possible. Whatever forces, social, political, or economic, may have contributed to these remarkable results, yet they never could have been achieved so long as the work of transport depended upon the pack-horse.[1] But the engineers have approached the problem in their own way, and their projects for the convenience of man have certainly been successful so far as the railways are concerned.

The natural complement to an improved system of inland communication was the improvement of navigation, for it was obvious that the people of these islands must always depend upon the fruits of other lands for a great part of their supplies; and the steamship was the natural successor to the locomotive. Like the locomotive, it is one of the things that were not, but its creation did not wait for the happy inspiration of a gifted inventor. It was sufficiently obvious to all men that Watt's condensing engine could be carried aboard ship and made to propel the vessel, and the cooling water was always at hand. The steamship is not the invention of anyone, but it is the creation of human intelligence

[1] It is hardly necessary here to inquire what progress could have been effected under a system of Free Trade in one country or of Protection in another country, under the régime of the pack-horse.

directed to the adaptation of the ship, the engine, and the propeller to their intended work and function, and it was achieved by the skill of such men as Penn, Maudsley, Napier, Laird, Samuda, Brunel, and Scott Russell.

The work of these first pioneers may perhaps be considered as extending to about the year 1860, when iron had completely taken the place of wood in shipbuilding, and the screw was rapidly taking the place of the paddle-wheel. Among the beautiful examples of their naval architecture we may recall such vessels as the Queen's yacht *Victoria and Albert*, the troopship *Himalaya*, the ironclad frigate *Warrior*, or the four mail-packets, *Leinster*, *Munster*, *Ulster*, and *Connaught*, which plied for many years between Holyhead and Kingston, with a speed of about twenty knots.

During this first stage of development the design of the marine engine had passed through a great many changes, but it was always a low-pressure condensing engine, and the steam was generally expanded in a single cylinder. At first the boiler pressure was not more than 7 or 8 pounds per square inch, and in 1859 it had only reached 20 or 25 pounds, so that the engines of a big steamer were often of impressive size and weight although working only up to a moderate power. Down to that date, indeed,

high pressures had only been associated with such engines as the locomotive.

In the later progress of steam navigation, down to 1900, the most conspicuous feature has been the notable increase in the efficiency of the engine. Its general design has seldom departed from the favourite overhead type, but the great improvement has been obtained by multiple expansion in two, three, or four cylinders, starting with a higher initial pressure, and this higher pressure had been rendered possible by the progress in boiler-making, and especially by the introduction of mild steel for the purpose. Thus in twenty years the boiler pressure had increased from 25 to 100 pounds, and had reached 220 pounds before the end of the century. In a modern steamship the work obtained from a ton of coal is more than twice as great as it was in 1860, and the advantage tells in many ways upon a long ocean voyage. A higher speed can be attained without increasing the consumption and storage of coal; or if the speed remains unaltered, the consumption of fuel is less and the cargo-carrying capacity by so much the greater. The further capabilities of the water-tube boiler and of superheated steam have yet to be worked out, but the recent introduction of the steam turbine is a step which promises soon to revolutionise again the practice of

steam engineering. With the general increase of ocean traffic there has been a simultaneous increase in the size of the steamship, and this again has been facilitated by the use of mild steel in shipbuilding. The largest Cunarder in 1859 was the iron paddle-steamer *Persia*, with a displacement of 6,000 tons and engines of 4,000 horse-power, while her place has been taken to-day by such vessels as the *Lucania* and the *Campania*, and even these are outrivalled in point of size by the *Cedric*, the *Oceanic*, and the *Kaiser Wilhelm II.*, the largest being the *Cedric*, with a displacement of about 32,000 tons, and a length of 697 ft. over all. It is remarkable, however, that all these modern vessels have only now attained to, without sensibly surpassing the dimensions of, Brunel's great steamer the *Great Eastern*, which was launched in 1859. The design of that great vessel has continued to command the respect of naval architects, but her career was a series of misfortunes, and probably her greatest fault was that, like Brunel's broad-gauge railway, she was too far in advance of the requirements of her time. We should remember, however, that her dimensions were adopted with a special object in view—it was that she should carry coal enough to enable her to reach India or Australia round the Cape of Good Hope, for the Suez Canal was not then in existence.

This incident reminds us that the steamship was only one half of the problem of navigation—the waterway was the other half, and its improvement fell more directly within the province of the civil engineer. At the beginning of the nineteenth century very little had been done in this direction. The old merchantmen had found access to our shores in some sheltered estuaries like the Thames and the Mersey, or in such natural harbours as Milford Haven or Queenstown, and a few small docks had already been excavated upon the banks of the Thames; but there was a great deal for the harbour engineer to do, and great progress was made in the first half of the century.

Breakwaters were built, or commenced, at Plymouth, Dover, Portland, Kingstown, Holyhead, Aberdeen, and some other ports. Smeaton had carried up the ingenious dove-tailed masonry of his beautiful tower upon the Eddystone Rock, and a large number of lighthouses had been erected all round the coast; while commercial harbours had been established at a number of points with convenient docks, basins, and quays for the loading and unloading of the ship.

The improvement of the waterway, for both naval and mercantile services, has perhaps been a more important matter for Great Britain than for any

THE "GREAT EASTERN" STEAMSHIP—LAUNCHED 1858. LENGTH OVER ALL 693 FEET

*Displacement as passenger steamer 27,400, as cable-ship 32,700 tons*

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Among the notable devices for establishing a freer and more rapid communication by land and by sea, we must include the communication of messages by electric telegraph. This invention was certainly a remarkable application of one of nature's sources of power to the use and convenience of man. The galvanic battery was indeed a prime mover (like the

heat engine) developing a certain amount of electric energy from a natural source; and although the electric power was extremely feeble, yet the current could be sent through many miles of wire, and with the aid of an electro-magnet and a code of signals messages could be instantaneously transmitted through very long distances. Thus electricity was first utilised for a service of incalculable value to humanity; and in the telegraph it was applied to a purpose for which it was peculiarly adapted, and which could not, indeed, be fulfilled by any other known agency of nature.

The telegraph was, from the first, the necessary complement of the railway service; and in a short time its lines had been extended, along with the railways, to every part of the kingdom. In many country districts private messages could only be sent from the nearest railway station, until the General Post Office had taken over the service. But the lines were then rapidly extended to meet the growing public requirements, and Sir W. Preece now informs us that the British lines of land telegraph have reached a length of 930,000 miles of wire—enough to go thirty-nine times round the world.

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navies—H.M. battleship *Agamemnon* and the U.S. frigate *Niagara*. The two vessels sailed in company from this side of the Atlantic, each carrying one half of the cable. Arriving at mid-ocean together, the vessels' heads were laid in opposite directions, and when the cable had been spliced between them, each ship sailed for its own country, paying out the cable as she went. The two ends were safely brought to shore, and messages of peace and goodwill were exchanged between Her Majesty Queen Victoria and the American President; but having delivered these messages, the cable became silent, for the insulation had broken down somewhere in deep water. The break, however, was located by means of electrical measurements at this end, and when the cable had been fished up at the point thus indicated, the injured part was duly found and repaired.

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To trace very briefly the progress of engineering in these directions, we may remember that at first the water-wheel was almost the only prime mover. Of course the fitful power of the wind had been used at

that time, and the windmill was built at any open spot that would suit the business of the miller. But most of the corn-milling, the wool-spinning, and the cloth-weaving machinery was driven by water-power, and the industries had been naturally located upon the banks of certain rivers where the necessary fall and power could be obtained.

Thus manufactures had been confined within a small area, but the restriction was entirely removed by the introduction of steam-power for the work of the factory, and by the simultaneous extension of railways; for the coal could then be brought to any part of the kingdom, and its conveyance from the pit-mouth to any railway-station in the North of England or in the Midlands could only form a very small item of cost.[1]

Wherever the manufacturer could find the best local facilities for obtaining the raw materials or the labour, or the best market for the finished product, there the power could be put down along with its textile machinery or other implements of manufacture. The steam engine and its driven machinery were housed together in one building, and the power was transmitted from one to the other by ordinary

[1] Manchester received its first adequate supply from the Worsley Collieries by means of the Duke of Bridgewater's Canal, which was built for that purpose.

shafting or other simple gearing, just as it had been in the older water-mill.

As compared with the water-power, it is obvious that the use of steam involved an annual expense in consumption of fuel, but the cost of coal in this country has been so small that it was far outweighed by the interest and depreciation upon the large capital that would be required for the permanent works of a large installation of water-power. Thus the great work of manufacture in Britain is now performed almost wholly by the power of the heat engine, and has grown to such dimensions that the work could hardly be overtaken by all the water-power that is practically available in the country.

But the conditions were quite different in some foreign countries. There were districts, for example, in Switzerland and in America, which did not possess any such facilities for the ready supply of coal, while in the neighbourhood were to be found great natural sources of water-power which had never been utilised —and mainly because Nature had not located her waterfalls with any special reference to the requirements of manufacturers in the nineteenth century. In recent times this local difficulty has been entirely overcome by electric transmission. Using a moderate current at very high potential, it is possible to convey a large amount of electric energy for a great

distance through a wire of moderate size, and by this means the power of the water-wheel is transmitted without much loss to distant factories whose situation can now be chosen (within certain limits) by reference to the requirements of business.

Owing to this difference in the natural conditions it was not to be expected that electricity could be so largely used in England for the transmission of water-power; but it has already found a profitable application in many steam factories, where it has been used, instead of the ordinary shafting, for conveying the power of the engine to the driven machinery. Of course the dynamo and the electro-motor add nothing whatever to the power of the prime mover, but they are machines of such high efficiency that, in many cases, they will convey the power with less waste than would be entailed by the friction of long lines of shafting and belt-gearing.

A review of engineering progress in any particular direction must always suggest that each advance has depended upon a simultaneous advance in other departments. The civil and the mechanical engineer have been indispensable to each other, and both of them have depended very much upon the progress of the ironmaker. The manufacture of iron and steel was a very ancient art; and its slow and costly methods had undergone but little change in any part

other country; it is certain, however, that our harbour engineering has not fallen behind the measure of its responsibilities, and its continued progress must have helped very largely to retain in British hands the chief share in the shipping industry of the world.

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Wherever the manufacturer could find the best local facilities for obtaining the raw materials or the labour, or the best market for the finished product, there the power could be put down along with its textile machinery or other implements of manufacture. The steam engine and its driven machinery were housed together in one building, and the power was transmitted from one to the other by ordinary

[1] Manchester received its first adequate supply from the Worsley Collieries by means of the Duke of Bridgewater's Canal, which was built for that purpose.

shafting or other simple gearing, just as it had been in the older water-mill.

As compared with the water-power, it is obvious that the use of steam involved an annual expense in consumption of fuel, but the cost of coal in this country has been so small that it was far outweighed by the interest and depreciation upon the large capital that would be required for the permanent works of a large installation of water-power. Thus the great work of manufacture in Britain is now performed almost wholly by the power of the heat engine, and has grown to such dimensions that the work could hardly be overtaken by all the water-power that is practically available in the country.

But the conditions were quite different in some foreign countries. There were districts, for example, in Switzerland and in America, which did not possess any such facilities for the ready supply of coal, while in the neighbourhood were to be found great natural sources of water-power which had never been utilised —and mainly because Nature had not located her waterfalls with any special reference to the requirements of manufacturers in the nineteenth century. In recent times this local difficulty has been entirely overcome by electric transmission. Using a moderate current at very high potential, it is possible to convey a large amount of electric energy for a great

distance through a wire of moderate size, and by this means the power of the water-wheel is transmitted without much loss to distant factories whose situation can now be chosen (within certain limits) by reference to the requirements of business.

Owing to this difference in the natural conditions it was not to be expected that electricity could be so largely used in England for the transmission of water-power; but it has already found a profitable application in many steam factories, where it has been used, instead of the ordinary shafting, for conveying the power of the engine to the driven machinery. Of course the dynamo and the electro-motor add nothing whatever to the power of the prime mover, but they are machines of such high efficiency that, in many cases, they will convey the power with less waste than would be entailed by the friction of long lines of shafting and belt-gearing.

A review of engineering progress in any particular direction must always suggest that each advance has depended upon a simultaneous advance in other departments. The civil and the mechanical engineer have been indispensable to each other, and both of them have depended very much upon the progress of the ironmaker. The manufacture of iron and steel was a very ancient art; and its slow and costly methods had undergone but little change in any part

of the world until the beginning of the nineteenth century. But from that time it has witnessed a long series of improvements which have been almost wholly due to British engineering.

The hot blast was introduced by Neilson in 1829, the steam hammer by Nasmyth about ten years later; and these improvements did much for the production of malleable iron, and for the saving of fuel; but it still required more than five tons of coal to produce one ton of good rolled iron. The old manufacture of steel from the best wrought-iron was still more costly, adding other tons of fuel in the successive processes by which the pure iron was again recarburised. The sword-blade of the old armourer was indeed as good a piece of metal as any that has been produced, and the quaint little pots and ovens and crucibles that were still used at Sheffield might be retained for the making of small cutlery; but the metal was not suitable for the building of ships, or boilers, or bridges, and the small-scale processes were altogether inadequate for turning out the millions of tons that were needed by engineers for such purposes, and for the rails, tyres, and axles of our fast-extending railways.

These objects were accomplished in 1856 by the regenerative furnace of Siemens' open-hearth method and by the Bessemer converter, producing

different grades of steel with a much smaller consumption of fuel than had hitherto been required for wrought-iron. At first the Bessemer process could only be applied to ores that were free from phosphorus; but a few years later the phosphorus was eliminated by the "basic" modification of Thomas and Gilchrist. Thus wrought-iron has been almost entirely superseded by steel, except for some special purposes: the material for our rails, tyres, and axles is furnished by the Bessemer converter, while the open-hearth process gives us the very ductile steel that is required for shipbuilding and for boiler-making. At the present time the British iron and steel makers are converting about fourteen millions of tons of ore per annum.

The use of iron, in any form, for purposes of bridge-building had been very uncommon before the year 1800,[1] although we find that, soon after that date, both Rennie and Telford were proposing to cross the Menai Straits by a cast-iron arch of large span. These bold designs were not carried out, but one of the finest early examples is Rennie's well-known bridge crossing the Thames at Southwark in three spans, and dating from 1815, when the Battle of

[1] A few arches had already been built of cast-iron, the first being a bridge of Telford's at Coalbrookdale, completed in 1779, with a span of 100 ft.

Waterloo was fought and Rennie's Waterloo Bridge was in progress.

The design of such arches had followed the lines of the earlier stone architecture, the iron panels being fitted together so as to take the function of arch-stones; and the material was indeed better adapted to withstand that kind of stress than any other, owing to the weakness of cast-iron under tension.

But in 1825 Telford carried his bridge across the Menai Straits upon a different principle, abandoning the arch, and relying upon the high *tensile* strength of wrought-iron bars, which he used as links for the chains of his fine suspension bridge. The main span has a width of 570 ft.; and the example has been followed in many other road bridges of somewhat similar dimensions, as at Battersea and at Clifton. But for railway purposes the British engineer has generally selected the girder in preference to either arch or suspension bridge, for he found in the wrought-iron and the steel materials which offered a high resistance to *all* the different kinds of stress which take effect in the members of a girder.

With such materials the engineer has been able to carry his lines of railway over rivers and estuaries, which could never be crossed by the old builders in stone or in timber, but he has not achieved this end by the mere substitution of one material in place

of another: it has been accomplished only by the development of new forms of construction, adapted to the capacities of the new materials, and adapted also to the various internal stresses, which have been investigated by analytical study.

Looking at the open network of a modern latticed bridge, or at the great cantilevers which stretch their arms across the Firth of Forth, we can, perhaps, hardly recognise in these complex structures any likeness to the parent type, which was a simple cast-iron beam; and yet they are all girders in various forms or stages of development. The functions of the simple beam have, in fact, been analysed into their component parts or elements, and each elementary function has been allotted to a separate member specially adapted to its own particular duty.

Thus the general line of progress, in the evolution of the girder bridge, has been "from simplicity to complexity of structure, and from obscure complexity to a defined simplicity of function."[1] Along this line of development we may recall a few notable examples, such as the hollow wrought-iron beams of the Britannia Bridge erected in 1850, the great truss built by Brunel across the Wye, and his braced combination of bow and chain at Saltash, the Warren girders of the Crumlin Viaduct, followed in later years by a number

[1] Herbert Spencer's line of progress.

of bowstring and lattice girders of various types, and, lastly, the Forth Bridge crossing two main spans of the unprecedented width of 1,750 ft.

This short review has led our thoughts in many directions already, but it would be very incomplete without some brief notice of the progress of municipal engineering, which has contributed very much to the health and the conveniences of life in our cities, by its works of water supply, drainage, and public lighting, and its lines of urban communication.

In the year 1807 one side of Pall Mall was lit by gas, and this appears to have been its first introduction into public streets, although it had been used in the Lyceum Theatre since 1804. By 1815 most of the London streets had been lit, and gas lighting was soon extended to every considerable town in the kingdom. This was a great improvement upon the old oil lamps and the watchman's horn lanthorn, which had served to make darkness visible at the street corners; and soon after 1860 it began to be supplemented by electric lighting. The arc light had been applied in the North Foreland Lighthouse in 1858. Since 1870 electric lighting has been extended to almost every large town and to a great many villages.

The first section of the underground railway in London was opened for traffic in 1863, and, with its

RENNIE'S SOUTHWARK BRIDGE OVER THE THAMES, 1819

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later extensions, has served to relieve the congested traffic of the streets; while street tramways were introduced (from America) at nearly the same date. Tramway lines have since been laid in most of our large towns, but the familiar horse-car is now rapidly disappearing from view, for the street traffic on such lines could be worked with much greater public convenience by a stationary steam-engine. In a few cities, like Edinburgh, this was effected by rope-traction; but in the great majority of cases the power of the engine has been conveyed with greater efficiency and convenience by electric transmission. The same method has been extensively used, in recent years, for urban and suburban railways, and as everyone knows it is now to be applied to the Metropolitan Company's lines.

The waterworks of London can lay claim to a considerable antiquity, for the New River supply was brought in as long ago as 1613 by Sir Hugh Myddelton, and most of the other water companies had commenced their operations some few years before the beginning of the nineteenth century. But while London continues to derive its supply chiefly from the river Thames, engineers have provided new systems of water supply for most of the large towns throughout the kingdom. The supplies have been obtained from various sources, but the engineer has generally

found reason to abandon the valleys and all populous districts, going far away up the hillsides in search of water of unimpeachable purity, and has found it in the mountain streams and in great collecting grounds upon the moorlands. From these elevated districts he has conveyed the water through long lines of aqueduct by gravitation, making use of the natural water-power to convey the water itself to its far-off destination. Thus Liverpool has been supplied from Vyrnwy, Manchester from Thirlmere, and quite recently Birmingham from Mr. Mansergh's great reservoirs in the Elan Valley, not less than seventy miles from the city.

The waterworks of Britain include many engineering structures which have surpassed, in some respects, the aqueducts of old Rome; but the English people have not cared to emulate the extravagant provision that was made for the luxury of Roman citizens—they have been content to bring into every town a supply of pure water, adequate in quantity for the "uses" of industry and the "conveniences" of domestic life.

This very imperfect story of engineering progress has been altogether too brief, and has left many points unnoticed; but it may serve to remind us of some of the good things that have been accomplished in the nineteenth century, and to show how engineers

have been working towards the fulfilment of their many projects for the use and convenience of man.

It is already evident that the execution of such public works must have been attended with far-reaching effects, and it would be interesting to discover how they have really affected the well-being of various sections of the community; but anything that can be said about this intricate question must be left for the next chapter.

## CHAPTER III

### THE PLEA FOR ENGINEERING IN ECONOMICS

WHEN Cornelius Vermuyden was employed by King Charles I. to drain the Lincolnshire fens, he planned and partly carried into execution the first of a series of engineering works which have added to the land of England an area almost as great as the whole country of Holland.

But the great utility of the project did not save it from violent opposition at the time. The original fen-dwellers had depended for their living upon the wild-fowl and the fish that could be caught in the swamps; and when they found their occupation gone they rose in revolt. The fact that, after many years of labour, some 600,000 acres of the best corn-land had been reclaimed for the country mattered nothing to them: they blocked the water-courses, cut the dykes, and restored the whole district to its primitive condition of uninhabitable swamp; and it would appear that even the patriotism of Oliver Cromwell was not broad enough to prevent him from taking part in the destruction.

We need not doubt that the fen-dwellers, from their own point of view, found some justification for their proceedings, and the incident only reminds us that progress has not been achieved without encountering such natural opposition at every step. The water-carriers in London did their best to prevent the introduction of the New River supply into the city; and at a later date we remember that the life of James Watt was in imminent danger from a Birmingham mob, who had raised the cry of "No philosophers," and had already burned down the house of his fellow-worker, Dr. Priestley, before they could be dispersed by the dragoons. Still later we recall the burning of agricultural machines by the farm labourers; and forcible protests of a similar kind were often repeated until nearly the middle of the nineteenth century.

In each case the working-man suffered a real injury in the loss of his old occupation; and when railways were first laid in any district they not only ruined the business of the coaches and canals, which had found employment for a large number of men, but threatened also to injure vested interests of many other kinds. They were opposed by landlords and tenant-farmers in all parts of the country, while the towns were so little in love with them that they compelled the main lines of railway to keep at a

respectful distance from their neighbourhood. If some of these supposed grievances were imaginary, it is certain that many of them were very real, and everyone knows what an immense injury has fallen upon the whole agricultural industry of our country, and all its dependent interests.

Engineering stands in need of some valid plea to justify the operations which have wrought havoc in so many directions.

On behalf of engineering, we may first notice one plea which might be urged, and often has been urged —it is that the individual losses have been recouped, or more than recouped, by individual gains of a similar kind.

The old occupations, which found employment for a certain number of working-men, have been replaced by new industries which now find employment for a still larger number, and at higher wages. And in regard to other classes of the community a similar argument might, no doubt, be stated: for if the railway, the steam engine, and the dynamo have wrought changes which have injured some sources of revenue, yet they have afforded a new and a wide field for the profitable investment of capital.

Such considerations have certainly had their weight in the past; and to-day the machinery of our factories is quite safe from attack, for its destruction

would obviously throw a large number of hands out of work; while the profits earned by the railways and by other works of engineering enterprise have come to form a valuable part of our whole national income.

Of course, this lamentably weak argument is *not* the plea on which the engineers have based their original programme; but it is evident that their projects could never have been carried out if they had not offered the prospect of a good return upon the expended capital. The prospect was not, perhaps, very clear so long as the scheme could only be seen upon drawing-paper, but the investor was abundantly satisfied as soon as the work was executed and earning a good revenue. Thus the first canals were only carried out by the individual enterprise of the Duke of Bridgewater, and at the cost of his private estate;[1] but within a few years afterwards we find that "an immense number of Navigation Acts received the sanction of Parliament, canals began to be freely quoted on 'Change,' and in 1790 the canal mania began. The *Gazette* of August, 1792, contained notices of eighteen new canals, and the premiums of single shares in companies had reached such figures

[1] It is said that the Duke had nearly come to the end of his resources before he could finish the Worsley and Manchester Canal, and was paying his engineer Brindley at the rate of three shillings and sixpence a day.

as £155 (Leicester), £350 (Grand Trunk and Coventry), and £1,170 (Birmingham)."[1]

All this was repeated on a larger scale during the railway mania, when Hudson was "Railway King"; and at a still later date we have seen a similar "boom" in the shares of electric lighting companies.

That British enterprise has yielded a ready, and sometimes profuse, support to such undertakings can never be a matter of regret on public grounds. It has had the disappointing effect of keeping down the dividends to something like a normal level; but it has promoted that public competition which seems to be a necessary element in the economic system under which we live. The holder of railway shares or debentures has not obtained, perhaps, a higher rate of interest than about 4 per cent. upon his invested capital, but railways have been multiplied until everyone has shared in the benefits of rapid and exceedingly cheap transport. It would be almost impossible to estimate the money value of this public benefit, but if the annual cost of moving 450 million tons of goods by railway were compared with the cost of its transport by road, the comparison would certainly show an annual saving of some hundreds of millions sterling. The railway system brings, therefore, immense gain to the country, but

[1] Jean's *Waterways and Water Transport.*

the larger part of the gain is reaped by the people who *use* the railway, and not by the people who derive their incomes directly from it.

Engineering enterprise of any other kind is subject to the same conditions; and its true value can never be measured by the profits it may yield to the capitalist, nor by the wages it may offer to any kind of labour.

In every case, however, we may expect that the economic problem will be looked at from different points of view, and will wear as many different aspects. The factory artisan can see very clearly that his prospects depend upon finding continuous employment at a good rate of pay. To him the wages are everything, and the productiveness of his work may count for nothing—or perhaps less than nothing, for if the work is done as slowly as possible, his labour will be in greater demand. He dreads "over-production," and must logically regard the employment of steam-power as a direct injury to the interests of his class.

On the other hand, the political economist has long been preaching a broader doctrine, insisting always that the material wealth of the whole community must depend upon the productiveness of industry, and that the general prosperity can only be ensured by the abundant production of those

things which form the necessaries and conveniences of life in proportion to the number of people who have occasion to use them.

The motto of the early engineers shows clearly enough that they were men of a similar faith, although they have naturally looked at the matter from their own special point of view. To them the whole economic problem seemed to resolve itself into a question of *work* that needs to be done and the *energy* that is needed to do it. The old economists[1] had already taken a similar view of the matter, but some of them appear to have relied upon human labour as the only productive energy —and every new labourer makes one more to be fed—while the engineers have enlisted on the same side the great forces of nature; and when these have lent their vast energies to the work, they have multiplied the productive power many times over without adding thereby to the number of consumers among whom the products have to be divided.

Thus if the application of power to our factory-work needs any defence, it finds its best plea in the wide benefits which it ultimately yields to the *user* of its products; and every project of the civil engineer must be judged by the same test—it will

[1] We may remember that in Adam Smith's time the "fire-engine," as he called it, was quite a novelty, and had hitherto done very little.

be justified in the long run if, in fair proportion to its cost, it contributes effectively to the use and convenience of man.

The agricultural interest in Britain has suffered loss, but engineering has helped to bring a cheap and abundant supply of food to the whole people of Britain. If the use of machinery has brought down the wages of the poor seamstress, the weaver, and the match-maker, it has supplied the whole population with the necessaries and comforts of life. The London water-carrier has lost his occupation, but the people of London have the water within every house, and ten times as much as they had before.

And the broad result is only to be measured by the average condition of each class in the community as compared with its condition in the eighteenth century, in regard to the possession of all those material things which go to make up the necessaries, the comforts, or the enjoyments of life, including all those facilities for travel, reading, and education which may contribute to its improvement.

## CHAPTER IV

### THE OCCUPATIONS OF THE CIVIL ENGINEER

IN following the engineers along the various lines of progress that have been traced in the second chapter, it has become very evident that the word "engineering" includes to-day a vast number of widely different occupations. The work that has been undertaken in so many different fields was a great deal more than could be carried out by one set of men, and it soon became clear that a division of labour was absolutely necessary. The making of engines and machinery was taken in hand in the shops of the mechanical engineer, while the civil engineer was engaged in carrying out his great works of construction in the field.

This division was soon followed by a further subdivision in each of the main branches, to the advantage of both. The mechanical engineer found as much as he could well do in the making of *one class* of machinery, and often confined his attention to the production of one special type in the particular class. Thus we find at the present day a number

TELFORD'S SUSPENSION BRIDGE ACROSS THE MENAI STRAITS, 1825

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of eminent firms who devote their ingenuity and their resources to the production of *each one* of the following classes of work or machinery :—

| | |
|---|---|
| Locomotives | Water-pipes and fittings |
| Marine engines | Gas-lighting plant |
| Mill engines | Hoisting machinery |
| Boilers | Wood-cutting machinery |
| Gas and oil engines | Textile machinery |
| Turbines | Corn-milling |
| Motor-cars | Bridge-work |
| Portable engines | Metallurgy |
| Agricultural machines | Electrical machinery |
| Hydraulic machinery | of all kinds |
| Pumping engines | |

In addition to all this, the mechanical engineer has often become the builder of warships, and the maker of heavy guns, armour-plates, turrets and their machinery.

The design of *all* kinds of machinery may be said to form part of civil engineering in its widest sense, but the main occupation of the civil engineer must lie in the design and construction of public works such as the following :—

| | |
|---|---|
| Bridges and viaducts | Landing-stages |
| Roads | Dockyards |
| Railways | Floating-docks |

| | |
|---|---|
| Tunnels | Waterworks |
| Street tramways | Drainage works |
| Canals and river-works | Aqueducts |
| Breakwaters | Reservoirs |
| Harbours | Irrigation |
| Lighthouses | Reclamation of land |

In connection with these works of construction—for their execution *and* their equipment—he will employ machinery of almost every kind that has been named in the first list; and in most cases it will be part of his duty to adapt the machinery to its special purpose, although its actual construction may be carried out in the shops of the mechanical engineer. Sometimes he may, with great advantage, adopt such forms and details of mechanism as have already been worked out by the skill and experience of the engine-maker: while in other cases he may be compelled to devise mechanical appliances of some special kind to meet the particular requirements of his work—such as pneumatic machinery for sub-aqueous tunnelling, hydraulic machinery for the equipment of dock-works or the regulation of water-supply, and many other kinds of special plant and machinery.

Between the two main branches of engineering there are some notable differences which claim our

It may be possible to carry on the manufacture of machinery successfully for some length of time upon purely commercial principles; but the civil engineer *must* be a man of some original resource and creative ingenuity, as well as practical skill and experience.

We may henceforth confine our attention to the special work of the civil engineer, and in due time we shall have to consider the nature of his professional duties and responsibilities. We shall find that his position may sometimes resemble that of the military engineer, but will generally find its closest parallel in the professional position of the architect. But to understand his complex relations with *men*, we should first consider in some fuller detail what is the nature of his occupation in dealing with *things*—what are the physical facts and problems that must engage his study, and what it is that the civil engineer and his assistants will find to do—in the field and in the drawing-office.

We may begin with the preliminary surveys.

Before anything can be done towards the commencement of any extensive public work, such as a line of railway, the ground must be carefully studied. Existing maps and plans will afford only a hazy indication as to the lie of the country: they may show, indeed, where the rivers run, and a route which is practicable for the water is often practicable

But the civil engineer works under happier conditions, which are almost the opposites of all these. His occupation is not a trade, but he is professionally engaged to prepare the designs for such public works as are mentioned in the second list, and to superintend their execution. These public works are not products of any manufacture, and they cannot be designed to one pattern nor made by one set of machine tools, and they cannot be carried out by one class of skilled labour. Their execution may employ the ironfounder, the smith, and the engine-fitter, but it will also require the co-operation of mason, bricklayer, carpenter, and excavator, and very likely of the sailor, the miner, and the helmet-diver; and the operations of these allied forces can never follow the order of a prescribed routine. Every new work brings its own problems—with new objects to be attained, new conditions to be met, and new difficulties to be surmounted.

In taking up the design of such works, there are no interests to be served by adhering to the lines of earlier examples, and the engineer is free to find his own solution for the problem. There is only one Dover Breakwater in the world, and only one Forth Bridge; and if we compare the great bridges of recent times we shall scarcely find two that are alike, for in each case the engineer has sought for the *best* means of attaining his end.

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for the railway, but the line must sometimes cross from one watershed into another, passing over intervening hills or perhaps mountain ranges. For his first exploration the engineer may very likely take with him nothing more than an aneroid barometer strapped over his shoulder, a field-glass in his pocket, and perhaps a box sextant or prismatic compass. But as soon as he can select the route that seems to be most practicable, that line of country must next be studied in all its details by a staff of engineering surveyors, equipped with levels and theodolites, or perhaps tacheometers. The staff will generally divide itself into parties, each party taking up a length of some ten or twenty miles; and if the work is far abroad, the expedition will require its camp or camps and its commissariat.

These men will presently have to construct detailed plans and sections, showing every important feature along the whole line of route; but the making of such plans is not the only nor the chief duty of the staff. The leader of each party must be something more than an accomplished surveyor, and should possess some skill and experience as an engineering tactician. He is the lieutenant in charge, and knows how to circumvent the obstacles of nature—he will have a quick eye for difficult earthworks, will know the best place to cross a river

when he sees it, or to throw a viaduct over a deep valley, or to drive a tunnel through a mountain range. For he must think out all these problems on the ground, and in looking over it he uses something more than a theodolite, for he sees things that are not as though they were. In the course of a month or two he has gradually worked through the length of his section, and his imagination has already drawn an outline picture of the railway as it is to be—the picture will be filled up by-and-by.

In due time the parties will meet at the several points of junction, and will then probably proceed to headquarters, where each party will prepare the completed plans and sections of the line of route. It would take too long to discuss here the purposes which are to be served by these preliminary plans: first, in obtaining the necessary powers from the English Parliament or the sanction of Continental governments, whose requirements in the matter of plans are far more exacting; and afterwards, as a basis on which the engineer will work out his detailed designs for each structure comprised in the project.

When standing orders have been complied with, however, the next duty of the engineer will be the preparation of these matured designs in the form of detailed "working drawings" or contract drawings.

And here we should remember that drawing is the language of construction, and a language which is universally understood among engineers of all countries and of every rank: so that one member of the brotherhood has no trouble in understanding the information conveyed by another, nor in reading his thoughts and intentions. Thus the picture, which had begun to photograph its outlines upon the vision of the surveying lieutenant, may be filled up in a drawing-office at Westminster: and when it is completed, it will convey the instructions of the chief engineer for the execution of the work in every detail.

The designs required for any such project as a line of railway will be numerous, and every one of them must be carefully thought out beforehand. The line could hardly be carried for twenty miles through a country like England without the building of some twenty or thirty bridges, and the drawings must include complete designs for all the bridges, culverts, viaducts, and tunnels, as well as the earthworks, permanent way and road, or river diversions. In each case the structure must be adapted to its special purpose, to its immediate surroundings, and to a vast number of local conditions, which must all be weighed in the engineer's mind. The questions that must engage his attention at this stage of his work,

and also during its later execution, are interesting enough, but they are so many that it would be impossible to refer to them all.

We can glance at a few of them if we begin with the bridges upon a line of railway.

A good many of these will be required for carrying the public or private roads over or under the railway. For the crossing of such small openings timber trusses were often used in old times, and are still used in America; but the British engineer will prefer to build in the more durable materials of good brickwork or stone masonry (unless he is driven to the modern substitute of Portland cement concrete); and if the local conditions permit he will adopt an arched superstructure, crossing over a road in one span, or over a deep cutting by a bridge of three or five arches, while in some cases he may find it advantageous to employ a superstructure of iron or steel. And in every case he will take care to make himself acquainted with the natural products of the locality, and the facilities or difficulties of transport: for in getting out his designs the engineer must always look ahead, and must provide beforehand, in his own mind, for *every* difficulty that will be likely to arise in their execution.

But the greater the difficulties the more pleasant will be the task, and the engineer finds himself

problem, and for one reason or another, the examples of the past will fail to satisfy all the new conditions, so that there is no prospect of anything like finality in bridge design. Quite recently the French engineers have built the Viaur Viaduct upon lines which form yet another new departure, and which may be said to combine in one structure the principles of the arch and the cantilever.

In designing the superstructure the engineer will do nothing by guesswork. He will carefully estimate the greatest load that the bridge will have to carry, making due provision for wind-pressure; and when all the internal stresses have been discovered by calculation, every member throughout the whole structure will be designed with a strength proportioned exactly to the burden it has to bear. This calculation fixes the stoutness of each member, and the stoutness determines its weight, while the weight of the whole steelwork in a large bridge is itself the most important part of the total load. The load can now be reckoned out more exactly, and if it exceeds the original estimate the members will have to be made stouter, but this will add to the load again, and it may prove a difficult matter to make the bridge strong enough to carry *itself*. In the Forth Bridge, for example, the heaviest train that crosses is an insignificant matter compared with the weight of the

BRUNEL'S SALTASH BRIDGE ON THE CORNWALL RAILWAY, 1859

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problem, and for one reason or another, the examples of the past will fail to satisfy all the new conditions, so that there is no prospect of anything like finality in bridge design. Quite recently the French engineers have built the Viaur Viaduct upon lines which form yet another new departure, and which may be said to combine in one structure the principles of the arch and the cantilever.

In designing the superstructure the engineer will do nothing by guesswork. He will carefully estimate the greatest load that the bridge will have to carry, making due provision for wind-pressure; and when all the internal stresses have been discovered by calculation, every member throughout the whole structure will be designed with a strength proportioned exactly to the burden it has to bear. This calculation fixes the stoutness of each member, and the stoutness determines its weight, while the weight of the whole steelwork in a large bridge is itself the most important part of the total load. The load can now be reckoned out more exactly, and if it exceeds the original estimate the members will have to be made stouter, but this will add to the load again, and it may prove a difficult matter to make the bridge strong enough to carry *itself*. In the Forth Bridge, for example, the heaviest train that crosses is an insignificant matter compared with the weight of the

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structure; and if the design for such a span were commenced upon the lines of the Saltash example, it would soon show itself to be an impossible project, for the weight of such girders would form a load very much greater than they could carry. But in finding his way through all these problems, the engineer does not walk blindfold, nor stumble upon impossibilities. He finds their practical solution by the scientific methods of the "theory of construction."

The crossing of very wide spans would be physically impossible without the aid of theory, but there still remain some other questions of a more practical kind—the foundations of the river piers will have to be carried down to a firm basis, and the steelwork of the great superstructure will have to be erected by some carefully devised process.

In some cases the piers of the bridge may be designed in the form of cast-iron cylinders like those which may be seen in the railway bridge at Charing Cross; and in many Indian rivers, where the bed consists of shifting sand-banks, these cylinders have enabled the engineer to carry down his foundations to a very great depth, where they can rest safely upon a firmer basis and beyond the reach of any scouring action of the flood.

But the method of sinking the foundations and

the construction of the river piers must depend upon local conditions. Sometimes the piers and abutments will be great structures of masonry, and to carry the masonry down through the water and the sand, the engineer may decide to use "caissons" of one kind or another. The caisson may sometimes take the form of a huge diving-bell filled with compressed air in which the workmen can operate; and the masons go on building their great pier upon the top of it, while the workmen under its base are gradually letting it down through the sand. In other cases it may be better to employ caissons which are so constructed that they can be floated and sunk by a different process. When the caisson has been launched from the building slip and towed out across the current, it is let down upon the bed of the river and sunk through the sand by dredging machinery worked from above water. These are only some of the many devices which have been employed in times past, and every new situation suggests the use of some new device for this difficult operation.

The same remark would apply to the later operation of building the steel superstructure, and the methods of erection are too numerous to be mentioned in detail. Arches and girders can often be built upon temporary timber staging, but the building of the stage would sometimes be a difficult or an

impossible task; and if several small spans are to be crossed by a *continuous* steel girder, the staging may be dispensed with. The girder can be gradually built up at the end of the bridge and launched forward upon rollers from one pier to the next.

The engineers of the Britannia Bridge built their tubular girders upon the deck of a pontoon lying in sheltered water, towed them out to their destination, and then lifted them to the tops of the piers by hydraulic presses. But a still bolder plan was followed at the Hawkesbury Bridge, where the girders were carried at such a great height above the deck of the vessel that they would pass clear over the piers of the bridge, and when they had been navigated to their right position, they were quietly let down upon their supports by scuttling the pontoon.

The cantilevers of the Sukkur Bridge were projected across the rapids, by carrying out one member after another by means of wire-rope overhead transport; while the Forth cantilevers were built out plate by plate and without any such aid.

Leaving the bridges, we may turn next to the operations of the water engineer, and we shall find that he works along similar lines, pursuing them in the same methodical fashion, and seeking always the best means for the accomplishment of a given end.

He will first ascertain the population of the town which needs the water-supply, and estimating for its probable increase within the next ten or twelve years, he will calculate the quantity of water that must be delivered for daily use in the town. The figure will govern all his later proceedings.

He will examine every natural source that promises to yield a supply adequate in quantity and in quality; the geological character of the neighbourhood may suggest the hope that it could be obtained close at hand by artesian wells or by steam-pumping; but he will often feel greater confidence in the distant mountain streams, whose purity is likely to be more *permanent* than that of any subterranean supply in the vicinity of towns. The engineer, however, takes nothing for granted, but obtains a chemical and bacteriological analysis of the water, and takes steps to obtain a periodical gauging of the mountain streams, repeated all the year round. From such monthly or weekly gaugings he oftens learns that, during the winter season, the yield of such streams is many times greater than he needs, but is totally inadequate during the later months of summer; and then it may be necessary to store up the superabundance of the winter rains in great reservoirs to tide over the summer drought.

The explorations of the water engineer lead him

far afield over mountain and moor; and the object of his quest is not the lakes but the rainfall. To depend upon a great lake would be something like living upon banked capital without an income—it must soon run dry, unless the quantity drawn out is made good by a perennial supply. Manchester, after all, is not supplied by Thirlmere, but by the rainfall upon a large catchwater area among the hills.

In finding the best place for his impounding reservoir, the engineer has a great many questions to consider—the collection of rainfall, the safe discharge of floods, the site for a dam or embankment, and the line and gradient of his aqueduct—for the gradient will govern the flow. Here, again, the surveying staff must take the field with duties which are not unlike those of the railway surveyor. These men, however, will not be trying to convey the water by long lines of arches like the old Roman aqueducts, but first, perhaps, by a tunnel through some mountain range—then by an iron pipe dipping down into a valley below and rising up again upon the side of a distant hill—then onwards by a line of culvert sweeping round the hill sides and nearly following their contour—then again dipping across another valley—and so on and on for the sixty or seventy miles to the distant town.

The aqueduct will be so designed that, when it is

completed, it will certainly bring to the town every day the required daily supply; but this does not complete the engineer's task—he must provide for its distribution and for a certain subsidiary storage in service reservoirs, large enough to meet the fluctuations in the *hourly* demand, and to supply the wants of the town in case of a temporary breakdown. Throughout all his plans and designs, from the catchwater area and the impounding reservoir down to the smallest pipe or valve, there will be no kind of random guesswork. Every dimension will be determined by exact calculation, and the results will be as certain as human foresight can make them.

A great municipal work of this kind may have its bridges or viaducts like a line of railway, but the greater part of the work is buried underground, and most people are entirely unaware of its existence—unless, perchance, a traveller in some remote country district happens to discover an isolated structure of singular aspect standing in the fields or woods, and learns by its inscription that it belongs to the waterworks of some far-distant city.

As the railway train passes from Warrington to Crewe, the passenger may see upon a neighbouring hill the outlines of a great Roman temple of circular form—it is really a water-tower upon the line of the Liverpool supply; and many such monuments upon

a smaller scale may be discovered by the diligent explorer.

Water engineering is a term that may be used to include many different operations—the rectification of rivers, the drainage of fens, and the building of canals, docks, harbours, and breakwaters, as well as works of water-supply. They all belong to the "Wasser-bau-kunst," as Dr. Hagen calls it; but marine works are generally undertaken by men who form a separate branch of the profession, and the harbour engineer devotes himself to his own special subjects of study.

His occupation brings him into continual touch with Nature, and his eyes are always open to notice what she is doing upon the seashore. In carrying out sea-defences, lighthouses, and breakwaters, he may have encountered some of her most violent forces, and he has also watched the more subtle advances by which she has obliterated the old Roman harbours and most of the Cinque ports. Along our southern coastline he does not fail to notice the persistent drifting of the shingle, the disintegration of the chalk cliffs, and the vast accumulation at the Romney Marshes.

On the shores of the North Sea he finds himself in the presence of conditions totally different from those which generally obtain upon our western coast, and

learns to distinguish between the "old seas" and the "younger" ones, which have not yet come to the limit of their tether, and are still shaping the destinies of the land. Here he studies with still greater attention the great movements of the sand as it is carried forward by wave and current to the making of nature's great submarine embankments; and he watches their progress as they try to close, and yet do not close, the mouth of some harbour or estuary by the formation of the "harbour bar."

In many harbours the "bar" will be the most serious obstacle to navigation, but its removal cannot often be successfully attempted by any mechanical appliances. The bar is itself the battleground of contending forces, and the engineer will rather try to enlist for his purpose one of these great natural "sources of power"—directing the tidal currents or the river-flow to the accomplishment of his object. The harbour engineer finds, therefore, an important subject of study in these contending forces, and especially in the tidal phenomena on which his operations so often depend. For in this matter nature has greatly favoured the British Islands, and has given us facilities which many nations do not possess. Many of our harbours would be almost inaccessible but for the daily advance of the great tidal wave as it makes the entire circuit of our coasts;

while the Thames, which is a very small stream, gives us a most valuable natural harbour such as cannot be found in the estuaries of the far greater rivers which debouch in tideless seas—such as the Danube, the Nile, or the Mississippi.

In commencing any work of harbour construction, the hydrographic survey will generally be the first step, and then each work must be adapted to all its surroundings—the winds, waves, currents, and tidal range—as well as to the mercantile traffic or the naval purposes which it may be intended to serve. It would take too long a time to discuss the many considerations that will be kept in mind by the engineer as he proceeds to design and to carry out such works—the construction of breakwaters upon stormy coasts, the design and erection of lighthouses, the building of deep-water quays and the methods of executing their submarine foundations, the excavation of basins and wet docks, and the construction of graving docks, lock entrances, and building slips, with all their equipment of hydraulic or mechanical appliances.

The first design of such works will demand all the skill, ingenuity, and experience that the engineer can devote to them, while their later execution will require his constant supervision for long periods of time. Of course this is true, to some extent, in railway engineer-

ing, bridge building, and works of water-supply, but the work of the harbour engineer is often of longer duration. A hundred miles of railway might perhaps be built in two or three years, while five or six years may possibly be required for the completion of a great system of waterworks, but the construction of harbour works will often go on from decade to decade, and the execution of a great national breakwater may sometimes extend over half a century.

## CHAPTER V

### THE DRAWING-OFFICE AND THE STAFF

IN looking over the purely technical work of the civil engineer, we have seen that it generally proceeds by three steps—the preliminary surveys, the complete design, and the actual execution of some public work, and they must come in the order here given. The surveys are a necessary basis for the complete design, and the execution cannot be commenced until the design has been drawn out in complete detail.

Ultimately the various operations involved in the construction of such works will be taken in hand by an army of workmen under the superintendence of a resident engineer, living always on the spot; or by contractors who employ their own engineering agents, staff, and workmen, and carry out the contract under the supervision of the resident engineer.

In either case the operations are not undertaken in any haphazard way, nor directed by the conflicting opinions of one man here and another man there. The entire army moves together under its lieutenants,

its captains, and its commander-in-chief. Every step in the plan of campaign has been arranged beforehand, and each step must lead on to the final completion of the whole work as it is intended to be by its designer.

To define exactly *what* the work is to be, in what *manner* and *material* it is to be carried out, and all the steps or details of its execution, the engineer must prepare the working drawings or contract drawings for each structure and every component part of it, as well as certain detailed specifications. All this is taken in hand in the engineer's office by the various members of the headquarters staff, including a sufficient number of junior and senior draughtsmen working under the direction of the chief.

Among cities that are distinguished as the favourite resort of different arts or industries, London is said to be the city which contains the largest number of civil engineers in proportion to its population; and their chambers are congregated mostly at Westminster, within easy reach of the Houses of Parliament.

In speaking of the draughtsman's occupations, it is first necessary to consider what is meant by the word "drawing," for it is almost as ambiguous as "engineering." In its popular sense it means perhaps nothing more than some kind of pictorial de-

THE FORTH BRIDGE—SPAN 1,760 FEET

lineation, but we have seen that for the engineer it is a language. Perhaps every picture speaks to us in a language of its own—a photograph of natural scenery may suggest the literary style of an auctioneer's catalogue, while the work of a great artist may become a poem.

In the hands of the engineer, drawing is used as the language of construction, and employed for many purposes. Sometimes its object is merely descriptive, conveying certain information about existing things, and its value will then depend upon the completeness of its description. A photograph may show us the outsides of things, but the sections and cross-sections of the draughtsman will reveal their true inwardness, showing not only the internal construction of a machine, but also its hidden principles.

The contract drawings which are prepared by the engineer will have to be regarded as legal documents, in which accuracy and completeness are always essential. They will be read along with the specification, and the draughtsman will carefully keep this special obligation in view.

But drawing, like any other language, reaches its highest purpose when it is used as a vehicle for conveying the thoughts and ideas of intelligent men. If there is any merit in the engineer's designs, it is to be seen in his original drawings, and they reflect all the

skill and forethought and ingenuity which have enabled him to adapt his great works of construction to their purposes and their surroundings.

The junior men in an engineer's office will often be engaged in reproducing upon tracing-paper the original drawings of the chief. Such duplicate copies of the design will be in the hands of the resident engineer and of the contractor during the execution of the work, and the structure when completed will itself be an exact reproduction, in stone and timber and steel, of everything that is shown upon the tracing.

The drawings will be used in the office itself for many purposes, including the exact measurement of the several items of work and material, so that when the "quantities" have been taken out, the engineer may be enabled to frame a detailed "estimate" of the probable cost of the whole work. And the specification will often be a lengthy document, describing every item in minute detail, so that its preparation will demand much care.

Hitherto we have not seen how the *original* drawings are produced, and all the rest of the work must depend upon these; but if we pass on to an inner sanctum, we may find the chief himself engaged upon such work, alone, or in conference with a senior draughtsman. The engineer is just commencing the

design of some new structure in a totally new situation. He has before him a perfectly blank sheet of paper, and nothing more. Upon that sheet will presently appear a drawing which is not copied from any older example, and which, indeed, will not represent anything in the world that *is* or *has been*, but something that is to be. Nobody knows as yet what shape the picture will take, for the man himself does not yet know. He would tell you, perhaps, that a week ago his mind was almost as blank as the paper; but he has been considering the conditions of his problem.

By what sort of process will the picture make its first appearance in his mind, and then upon the paper? Is it the "scientific use of the imagination"? Scarcely that—for science is not generally occupied in designs, and a fertile imagination working at random would only produce random ideas. The process must be something far more definite and rational: the man's thoughts must travel in lines that will lead to the desired end, and by ordered stages, each step being taken with the end clearly in view and with a constant watch upon all the surrounding conditions. Perhaps the faculty is partly acquired by practice, and in beginning his task he will lay out the invisible line of thought as methodically as he lays out a line of railway.

One thing, however, is certain—the picture will appear in due time upon the paper, for it must be done; and when it appears it will bear the impress of the man's mind. The designs of any old master like Brunel are as clearly marked with his own individuality as are the paintings of Constable, although in a totally different way.

We can imagine how much is comprised in such work if we remember that the Forth Bridge, in all its details, had to be designed in the engineer's office at Westminster before it could begin to make its appearance upon the Firth of Forth. But the same creative kind of work has to be done every day upon a smaller scale in every engineer's office.

There is one season of the year when the office shows signs of more than usual activity. Men of business and members of Parliament have come back to town after the August holidays with freshened vigour, and this is the sowing time for enterprise.

Corporations, directors, and company promoters begin to think again of some cherished scheme, and they know that if anything is to be done for the next year or more it must be put in hand at once, for the plans must be deposited in Parliament by the end of November. There is a great deal to be done, and no time to be lost. The engineer is con-

sulted, and a surveying party immediately takes the field to prepare the "Parliamentary survey."

While this party is at work in the field, "Standing Orders" will be diligently consulted, and they show that "public notices" must first be issued by advertisement in certain successive numbers of a local newspaper. These notices must describe the nature of the proposed work, and the line that it will follow, in terms that can be understood by all whom it may concern. The surveyed route must therefore be fixed, within certain "limits of deviation," in due time for the first issue of the notices. In these matters of legal formality, the engineer will generally have the assistance of a Parliamentary law agent, whose special experience will be valuable in many of the proceedings which have yet to follow.[1]

When the survey has been completed, with the aid, perhaps, of ordnance maps and plans, the whole staff will be busy with the plotting of Parliamentary plans and sections. If the work is in England these

[1] A finger-post, celebrated in story, is said to stand somewhere upon the Scottish moors, informing the traveller that "if he cannot read he may just speir at the blacksmith's"; but the story was eclipsed by the youthful engineer who began his advertised notices by saying, "The proposed line of railway will commence at the point marked 'A' upon the plan."

plans will be prepared in a special form and for quite special objects. They have but little reference to any questions of engineering construction, and cannot serve the purpose of the later working plans. Their special object is rather to illustrate, for the information of committees and of interested parties, the nature and extent of the powers that are sought by the promoters, and the manner in which the proposed work might affect the landed interest of proprietors, and all industrial, parochial, municipal, county or imperial interests.

The plans, therefore, will not give much information about the work itself, but they will carefully show every county, municipal, and parish boundary, and with minutest care every building, yard, field, and road, which will all be numbered and referred to in a "Book of Reference." The drawing of these details is a laborious task, and when it is done a large number of duplicate plans and sections must be prepared; for a separate deposit is required, not only for Lords and Commons, but for each one of a great number of officials, including the clerk of every parish touched by the line.

The work could hardly be done in time without the aid of Parliamentary lithographers, whose several studios are to be found in close proximity to the offices of engineers in Westminster; and these firms

will have a vast amount of work to do, as they receive sheet after sheet from neighbouring offices. For some weeks before the last day for deposits their skilled writers and engravers will be occupied night and day without intermission.

As the time draws near to its end, the work that still remains to be done in the engineer's office will often seem to present an almost hopeless task, but it is undertaken with a spirit which cannot fail. It is not unlikely that for two or three days the draughtsmen may have to work for twenty-four hours a day, but a failure is a thing unheard of, and the deposits are made within the prescribed time, although some of the copies may have to be despatched by special messenger or special train to reach their destinations before the expiration of the last hour. Later on these plans may have to run the gauntlet of opposition in Parliament, for there is seldom a lack of opposition; but the conflict is not to-day what it has been in the past. In older times Bills were occasionally thrown out for the non-compliance with some technicality in the Standing Orders, but opposition on Standing Orders is now very rare. It was also customary at one time to subject every scheme to intricate discussion upon its engineering merits, and engineers were invited to offer contradictory opinions upon such technical questions. But the procedure is

now changed. The engineer will still have the duty of defending his proposals before a committee of the Lords or Commons, but the defence will generally be upon broader grounds.

## CHAPTER VI

### THE ENGINEERING PROFESSION

AS a fish in the water, so the engineer finds his natural element in the pleasing occupations that have been described in the foregoing chapters, and in the equally delightful study of those great principles in physical science which govern all nature's operations, and must therefore govern his own.

But the closing paragraph of the last chapter reminds us that the civil engineer will always have his relations with men as well as with things; and the financial scale and magnitude of his public works are enough to show that these relations are always complex and important.

The professional duties and responsibilities of any engineer will obviously depend upon the particular position that he may occupy, and we may begin with that of the Engineer-in-Chief. His Parliamentary duties in connection with any work entrusted to his charge have already been mentioned, and his clients will depend upon his evidence in Committee as the

main support of their cause. At the same time his services may occasionally be retained in connection with other Bills in Parliament relating to works outside his own practice.

But we must pass on to the wider and more onerous duties which arise in the actual execution of his works of construction. Very generally these works will be carried out by contract, although it may sometimes happen that the engineer will see reason to recommend that his employers should proceed without the intervention of a contractor, purchasing their own materials, plant, and machinery, and employing their own workmen. In such exceptional cases the chief engineer, with his resident engineers and assistants, will have to take up the duties which generally fall to the contractor's engineering staff. What those duties are may presently be considered, but just now we may confine attention to the more usual system of carrying out works by contract, and the engineer's position under that system.

Here we shall find that he has really inherited the older customs, traditions, and methods which have long been followed in the professional practice of the architect; but he enters upon the position knowing full well that the contingencies and difficulties which lie before the contractor and himself are far greater than anything that the builder and the architect have

to contend with. The same "law of contracts," however, applies to both classes of work.

The architect, when called in by his client, had first drawn out plans and specifications for the proposed house, and when these were approved by the client he proceeded to draw out a contract between employer and builder for the due execution of the work. The drawings and specification taken together must define for the builder exactly what it is that he is expected to supply and to do in consideration for the money he is to receive; and they must define for the employer exactly what it is that he demands and is entitled to expect in the finished building.

To avoid any misunderstanding, it is obvious that the plans and specifications should be clearly apprehended by both parties; but a difference of opinion may easily arise between employer and builder as the work goes on, and an appeal must be made to the specification. The architect was generally appointed under the contract as an independent referee on such questions, and the builder was bound to comply with the plans and specifications in every respect to the architect's satisfaction. But experience showed that with every precaution it was not always possible to avoid the occurrence of wider and deeper differences between the two parties who are financially interested, and an ultimate appeal to arbitration was

generally provided for in the contract. The arbitrator nominated in the deed might either be the architect of the work or some other architect to be named by the President of the R.I.B.A.

In applying this accustomed system to the execution of public works, the chief engineer has to take all the duties of the "architect," the "builder" becomes some great contractor for public works, while the "employer" may be represented by a public company or their board of directors, or by a syndicate, a municipal corporation, or a county council.

But here the responsibilities of the engineer are especially onerous, and for several reasons.

We may notice, first, that in order to define the extent and scope of the contract, the architect would have to think of every room in the house, but the engineer will have to think of a thousand things which have not their like elsewhere, and many of them are discoverable only to his own foresight.

When every detail has been studied and worked out upon the drawings, he may perhaps be fairly sure that nothing has been forgotten—every visible thing has been completely shown and described, but there still remain the *invisible* things which cannot be shown upon any plans, and it is here that his greatest difficulties will be found.

For example, the engineer cannot see what is

VYRNWY DAM: LIVERPOOL WATER SUPPLY

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below ground, and some of his costliest operations must depend upon what he may there discover. Every excavation that is opened up for deep foundations, or cuttings, or tunnels, is almost sure to reveal some unexpected feature which could not have been foretold by engineer or geologist, or ascertained by borings.

The digging of a concrete trench beneath some reservoir embankment may reveal an unsuspected vein of permeable material, and the trench may have to go fifty feet deeper than was intended. A bed of quicksand may be struck in the sinking of some shaft, or of some cylinder foundations; and a radical change must at once be made, either in the method of procedure, or in the mechanical appliances, or possibly in the design of the structure itself. Or again, if such features are encountered in driving the "heading" of a tunnel, the engineer may have to meet the difficulty by new tactics, involving many changes and possibly the employment of a "Greathead shield" and costly pneumatic appliances.

With many such experiences in his memory, the engineer knows full well that when he is framing a contract for his employers, he is preparing to lead an advance against nature in the face of masked batteries, that his tactics will have to be chosen according to the enemy's position, and that a change of front may

often be necessary to save the fortunes of the day. There is no War Office that would tie the hands of its generals to a prescribed line of field operations, and for the same reason the hands of the engineer must be perfectly free.

To adapt the contract system to such contingencies as these, and many others of a like kind, is not an easy problem; and in drawing the "conditions of contract" the engineer will generally prefer to co-operate with the law agent who may represent his clients. In truth, there are at least four parties who are concerned in this agreement—the company, the engineer, the contractor, and Nature—the fourth party may not be mentioned in the deed, but she will not consent to be left out of the final reckoning.

Accordingly, the deed of contract must define the position and the powers of the engineer with especial reference to his dealings with the fourth party. If the operations are to be successful, he must be free to adapt his methods to the circumstances, to modify his designs if necessary, and to order "extra works." Along with this requisite, it is, of course, necessary that the relations between the employer and the contractor should be adjusted with fairness to both parties, and the contract may take one of several alternative forms.

In the "lump-sum contract" the whole of the

contingencies are intended to fall upon the contractor, and he will reckon the risks accordingly. In this case he must include in his own estimate of cost a sufficient provision for insurance against natural risk. It may sometimes be over-estimated, and if it is under-estimated he may find himself unable to complete the works.

On the other hand, a "schedule contract" may be so framed that the employers undertake their own insurance, as against the unforeseen and incalculable natural difficulties, leaving the contractor to undertake all responsibilities of the more ordinary kind, and to deal with all such contingencies as are commonly inherent in every trade. The schedule contract may be drawn in two or three different forms, but in general it will be accompanied by a detailed "bill of quantities," which have been calculated either by the engineer or by a firm of "quantity surveyors," and with due provision for all the different classes of extra work.

It would be impossible within the limits of this chapter to describe all the numerous vicissitudes of contract work, as they are known to the experience of engineers. It is enough to say that they will often impose upon the chief responsibilities of a most onerous kind; and we must not omit to mention the duties which he may sometimes have

to undertake as sole arbitrator in the settlement of disputed contracts.

If we now turn to the resident engineer, there will be no difficulty in realising his position in the field, and his varied responsibilities. He acts on behalf of his chief, and if the work is extensive, he will be assisted by several junior officers, who will probably lay out the lines of the work, and keep constant watch over the operations in different parts of the field. These junior lieutenants will keep in continual touch with their captain, while the resident will always be *en rapport* with headquarters. The distinguishing virtue of these field officers is that they know when to obey, and they know when to do something else. They have before them the plans and specifications, and also further detailed instructions, both written and verbal, and any departure from orders would be a serious matter for the officer, and yet the man would be of little use unless he could act for himself upon emergency. If a change of tactics in this warfare with nature should be suggested by any threatened attack, the resident will never wish to take the responsibility without immediate conference with his chief; but if the emergency calls for prompt action he must not hesitate, and if he uses the blind eye at the *right* moment, he will only be congratulated.

Among the professional occupations of the civil engineer, we certainly must not omit to mention those of the contractor's engineering staff, although it would be quite out of place in this volume to enter upon any description of the contractor's important business, or any of his great financial operations. The part that he has played in the actual extension of engineering work has been probably quite as valuable as that of the professional engineer, and tribute has already been paid to the enterprise and the indispensable business capacity of such old pioneers as Peto, Brassey, and Betts, while everyone knows how much the world is indebted to the later work of such men as Sir W. Arrol. Very often the contractor is himself an engineer, eminent in skill and ingenuity, while his chief engineering agent must always be a civil engineer, for he will be entrusted with duties and responsibilities which, in some cases, are not less important than those of the company's staff. If the work is an extensive one, the chief agent will be represented in the field by a number of district agents, each of whom is an engineer, assisted by a local staff of juniors; and the allied forces of the company and contractor will hold many councils of war in the course of their operations against the common enemy.

The distinguishing occupations and duties of the

contractor's engineer are already suggested to us by what has gone before. He will have to organise the entire army of operatives in all its branches, and in every part of the field he must direct their daily operations for the accomplishment of his end—which is the ultimate completion of the work as required by the company's chief engineer. He must obtain or manufacture all the materials required for its construction, and he often finds that he has to manufacture them. He will have to design and to build sheds, warehouses, mills, and a number of temporary works, including very often temporary railways for the conveyance of materials, and workshops for the production or the maintenance of machinery. He will often employ locomotives, railway waggons, dredging plant, steam cranes, pumping machinery, electric lighting plant, and an endless list of mechanical or electrical appliances. It is obvious, therefore, that he must lay out his own line of operations by his own skill and foresight, although at every step he may have to comply with all such special conditions as may have been dictated by the judgment of the company's engineer in the ultimate interests of the completed work.

It will readily be seen that all these men, on both sides, are placed in a professional position of confidential trust, and while the duties of the contractor's

staff are more varied, they are not less onerous than those of the company's engineers. But they have the satisfaction of knowing that the contractor is a man who is himself acquainted with their difficulties, and can appreciate the vicissitudes of their conflict with nature—an advantage which the chief engineer does not always possess.

Hitherto we have confined our attention to the execution of new works of construction, but the engineering profession must, of course, embrace a great number of men who are engaged as permanent officials; for the conditions of modern life depend upon the *continued* exercise of engineering skill at every point. It will not be possible, within the limits of this volume, to obtain anything more than a brief glance at these numerous occupations.

Each of the large railway companies has its permanent staff of engineering officials, including not only the locomotive department, but also an engineer's office for the maintenance of works, and often a separate office for the construction of extensions.

Every large town or city must have its municipal engineers, and they will often preside over different departments. The city engineer, the water engineer, the gas engineer, and the electrical engineer will all have their separate offices and assistants.

In the same way every harbour board, lighthouse

board, or dock corporation must retain its permanent staff of engineering officials, as well as every river conservancy. With all these men engaged in the occupations of civil life, we must place also the civil engineers and assistant civil engineers employed by the Admiralty in connection with naval harbours, dockyards, and coaling stations at home and abroad.

If we turn for a moment from civil to mechanical and electrical engineering, we may remember that the making of engines, dynamos, and motors has now become a regular manufacture. Large sums of capital have been expended in establishing the workshops and machinery by which they are turned out, and their continued reproduction does not require in every case the expenditure of thought and labour upon a new design: but a certain number of salaried officials will nevertheless be retained, and every large shop will at least have its manager and its drawing-office staff.

At the same time the maintenance and the management of machinery will always require engineering skill; and in this connection we cannot forget the important duties of the engineer officers in the naval and in the mercantile marine: for every warship to-day is a complex fighting-machine, filled with appliances mechanical, hydraulic, and electrical from stem to stern. All these appointments, however, lie outside the range of civil engineering.

In conclusion, we may notice that the civil engineer will frequently be working in co-operation with the members of other professions: the barrister and the law agent will have their relations with him in Parliamentary committee rooms or in Court of Arbitration, while he may often be connected with the architect or in consultation with the chemist or the geologist. Whenever the consulting engineer is called upon to report upon questions which involve matters lying outside the proper range of his own profession, he will prefer to call in the aid of the specialist: thus he will depend upon the chemist for the analysis of water, and upon the geologist for many questions that may affect the character of his Report. He will find his responsibilities wide enough without seeking to extend them.

## CHAPTER VII

### SCIENCE AND ENGINEERING

IN speaking here of pure science, we shall be almost wholly concerned with the three great divisions, namely, mathematics, physics (or natural philosophy), and chemistry, which deal with the known phenomena of inorganic nature: and if these three are not the only "positive sciences," they are, at least, pre-eminently entitled to that name.

Of course, engineering is not a pure science like one of these, for although its methods may be very similar to theirs, its objects are quite different. The one declared object, and perhaps the only proper one, for the pure scientist is the acquisition of knowledge for its own sake, and we all know how greatly his discoveries have added to our knowledge of the universe: but he has nothing to say about the adaptation of means to a useful end; if he has contributed to the "use and convenience of man," he has done so inadvertently, and we sometimes find him protesting his innocence of any such object or intention.

Engineering and medicine must stand by themselves in this matter, and while they follow Bacon's philosophic ideal, they must accept the reproach of working for an object that shall be useful to mankind.

To distinguish engineering from the pure sciences it has often been called an "applied science," and yet this term might be easily misunderstood. Its true character has been illustrated to some extent in the preceding chapters, and we have seen that engineering does not consist in the mere application of mathematics, physics, or chemistry, and that it demands the exercise of some faculties which are not called for in the pursuit of science.

But science has framed for us its invaluable theories, explaining in rational terms the universal principles of Natural Law, and there is nobody who needs this kind of knowledge so much as the engineer; for in every branch of his profession he meets the great forces of nature, and he can scarcely hope to deal with them successfully unless he understands them. Such knowledge is, therefore, a source of power for him, and he must adapt, convert, and apply it to his own purposes—for his problems are quite different from those of the physicist, and he may often have to seek out truth by his own exploration of fields which have not been touched by pure science.

There is, therefore, a distinct science of engineering,

which, like physics, is based partly upon experiment and partly upon the exercise of pure reason. The engineer must frame his own theories, and like the theories of the scientist, they will be the most rational explanation that he can give for the known facts, or the best answer that he can find for the questions which confront him in his own practice.

In the Prologue to Rankine's work on Civil Engineering we have, from that master of science, a learned essay upon the fallacy of the supposed antagonism between theory and practice.

We often hear it said that things which are true in theory are generally untrue in practice, and if the proverb is only a contradiction in terms, it has served to throw doubt and discredit upon the use of scientific method in engineering. In truth, it can mean only that our theories are sometimes incomplete, owing to the limitations of human knowledge, and it cannot mean that we should dispense with the use of rational methods.

Rankine's essay reminds us, however, that a very real antagonism existed for a long time between two opposite schools of engineering, and mainly on this question. Thus Smeaton is said to have expressed the greatest mistrust for what was called theory, and for people who would thrust it into practical matters; and yet he was himself the writer of many admirable

ADMIRALTY PIER: DOVER HARBOUR OF REFUGE

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papers upon the scientific principles of engineering. The fact is, that down to Smeaton's time science had not been much occupied with the *actual* problems of engineering: its methods were often based upon certain assumptions which were convenient for the mathematician, but were far removed from the actual facts; and theories of this kind could be of no service to the engineer. So the practical man left the theories alone, just as the scientist had left the hard facts alone, and each went his own way—the man of science in the academy and the practical man in the field. Their paths lay far apart, and as they seldom met, neither could get much help from the other.

All this time, however, the practical man was certainly following his own "theories," and they were often inexact—they needed to be explicitly framed in the language of science, and based upon the practical facts that were known to him. For many years the mathematician, the physicist, and the engineer have been working together in this direction, for the embers of the old controversy have nearly died out, and it cannot be said to-day that the engineer is in one camp and the man of science in another.

The practical uses of science in engineering may obviously include the following: To discover and express the truth about things as they are in nature

—to examine or demonstrate the principles on which the engineer's projects may depend—and to suggest to him some expedient which he might usefully adopt; but in modern times theory has found a more general use in the necessary *keeping of accounts* with nature. For the engineer has large transactions with nature, and the book-keeping is quite as important here as it is in any money business.

The bridge-builder, for example, must calculate all the destructive forces that are engaged against him, and their effects upon all the internal members of his structure, and on the credit side he must set such countervailing forces or resistances as shall be adequate for his purpose. Again, if his work lies in the employment of power, and its transformation from one kind of energy into another, the engineer is constantly undertaking some process of conversion, and the process is always an exchange—sometimes from the current coin of one realm of nature to that of another; but always an exchange in which nature keeps strict account, although the engineer knows that he will get his proper value if he can arrange the transaction without waste. In every department the practice of modern engineering will proceed, in the same way, by precise measurement and calculation of all the quantities that may be concerned.

The draughtsman and the surveyor must evidently

depend upon the principles of geometry for all their work in the office or in the field. The propositions of Euclid and the methods of trigonometry will be studied not merely as an exercise for mental training, but in view of practical objects which will lend them an additional interest, and will give rise to a number of new problems.

But geometry will also be used for other and quite different purposes: for the lines and areas of a diagram may be understood as representing all sorts of quantities, visible and invisible. Instead of measuring the actual lines and areas which the surveyor has to delineate upon his plan, they may be used to represent forces, moments, and stresses—or pressure, volume, and work—or volts, ampères, and watts—or temperature, entropy, and heat. It is here that the engineer finds the great value of analytical geometry, for it not only illustrates the relations between certain algebraical functions, but also between those invisible things which he is constantly dealing with. If he draws out the "conic sections" and their derived curves, it is not to trace the form of any cone, nor to illustrate the values of $x$ and $y$, but for some very different purpose—it may be to study the expansion of a gas, or to find the stresses in a continuous girder, or to solve some other out of the many problems which can best be treated by such methods.

For many of his calculations he will need all the help that he can obtain from the use of mathematics; he will constantly find occasion to employ some of the well-known methods of algebra, though others may be of little service to him; and he will find his best instruments of research in the differential and the integral calculus. But all these methods will be only a means to an end, and in using them his mind will be fixed, not upon the process or the symbols, but upon the actual conditions of the physical problem which he is trying to solve.

Passing on to the realm of mechanics, he will have to deal, not only with space, but with force, matter, and motion, measuring them all in suitable units, and studying the relations between them. The main principles of the science are as old as Sir Isaac Newton, and are, of course, applicable to all material things—to the governor-balls of a steam engine just as certainly as to the planets. Its study may be taken under the two heads of Statics and Dynamics, and the first will be applied by the civil engineer to all those structures which are intended to stand, and not to move: it will form, therefore, the groundwork of his theory of construction.

A complete theory of construction has perhaps not yet been written, but the books and the scientific papers which deal with the subject in its many

branches would already suffice to fill a small library. A large number of practical questions can be treated by the simple principles of statical equilibrium, and they will serve, first, to examine the stability of a structure or intended structure, and, secondly, to discover the magnitude of unknown forces and stresses.

Looking first at the question of stability, we can easily see its importance in the theory of arches and suspension bridges as well as in the equilibrium of floating vessels.

Probably the old Romans did not know that the curve which is naturally assumed by the flexible suspension chain, when hanging across a span, would give them a correct outline for an arch carrying the same load, if only the curve were turned upside down. They must have learned by experience how to build their semicircular arches with unfailing success, but they could not venture to design such masonry bridges as those which now cross the Thames or the Seine, and no modern engineer would venture to do it without consulting the theory of equilibrium.

In like manner the shipbuilder may successfully, and without much calculation, build one vessel after another upon similar lines and with a similar distribution of loads; but the engineer will often have to design floating caissons and pontoons, whose form

and whose manner of loading are quite unfamiliar to the practice of the shipbuilder, and he must carefully study the theory of stability if he does not wish them to "turn turtle" as soon as they are launched.[1]

Turning next to the design of braced girders and cantilever bridges in iron or steel, we meet with another group of questions relating to the strength of each part, as well as the stability of the whole work. No engineer would now design such girders without calculating the stress that each member will have to bear, and very often this will be done by the "method of moments," which is a simple application of principles of equilibrium. Whenever a merchant uses the steelyard to weigh his goods, he is really determining the magnitude of an unknown force, and the engineer finds the unknown stresses by a process which is equally certain—*weighing* them, in fact, and using the bridge itself as an imaginary steelyard.

But bridge calculations are not always such a simple matter. In the case of an ordinary steel arch or continuous girder, the stresses can only be discovered by a complex analysis which takes account of the elastic bending of the structure; for

[1] The problem of navigation upon water does not begin with questions of power and propulsion, but rather with these questions of stability; and whenever aerial flight or navigation may be practically taken in hand by the engineer, his first study must be directed to the stability of the airship.

if the steel were not elastic, the stress would often be incalculable.

However, the calculation of stress is only one-half of the problem, and the "strength of materials" is the other half. Here also their elasticity is an important question, for it sometimes governs the strength, as it does, for example, in a long and slender column. All these matters are, of course, subjects of experiment, and the engineer will make frequent use of the testing machine to ensure the safety of his work.

It may be said of the entire theory of construction that it has grown up along with the development of engineering practice, sometimes following and sometimes leading it. There was probably no written theory of arches until after the Romans had built them, and a new departure in practice has often called for an extension in theory. But the study of these scientific principles has suggested most of the modern improvements. It has directed all the developments of iron bridge construction, and is to-day the only possible guide for the design of large bridges.

If we now go on from structures to machines we bring in at once the element of motion—for machines are intended to go—and we pass from statics to dynamics. The casual visitor, looking at machinery

occasion may require. This is generally the function of such mechanism as wheels and axles, belts and pulleys, shafting and gearing; and they all consume some part of the original power in frictional work, transmitting only the remainder for the performance of "useful work." For every transaction of conversion or exchange nature keeps a strict account, and the engineer will do the same: the "energy expended" appears on one side of the account, and the "work done" is to be entered on the other side. There is always some loss on the exchange, owing to wasted work or lost energy, and the useful work is the net balance.

In electrical engineering, again, the "transformer" and the "rotary converter" are machines which have similar functions to fulfil—for electrical power is the product of the current and the electro-motive force. Thus if we have a given power, we can use these appliances for putting it into convenient shape —the "step-down" machine will give us a larger current at lower voltage, while the "step-up" will turn it into a small current at very high voltage, and in this latter shape it can be more economically transmitted through a long line of cable. Here, again, there is an inevitable loss on every exchange, but in these electrical machines the losses are very small.

The *actual transformation* of energy, from one *kind* into some different kind, is another of these transactions with nature, and it is like an exchange from French money into English, or the converse. For example, when electricity is employed by engineers for power purposes, the *electric* energy is always produced by the *mechanical* energy of the steam engine or of the water-wheel, and then the power of the electric current is reconverted into mechanical power. Nature has only one rate of exchange for the transaction in either direction, and it has been ascertained with great exactness by the electrician. The rate never varies, and one horse-power is always equivalent to 746 "watts," or one kilo-watt to about 1⅓ horse-power—the watt and the horse-power being the current coins in these realms of science, like the franc and the pound sterling.[1]

As between mechanical and electrical energy, we may regard magnetism as a connecting link. The mechanical force which actually propels the electric tram-car is the force of magnetic attraction and repulsion; and when the steam engine is driving a dynamo it expends its whole power in working

[1] The watt being a measure of electrical *power* is the product of volts multiplied by the ampères of current. The parallel would be more exact if we likened the transaction to an exchange between francs per annum and pounds per annum.

in motion, is perhaps only interested in seeing the wheels go round, but the object of the engineer is always the performance of "useful work," and the work can only be done by a corresponding expenditure of "energy." The two quantities, work and energy, are measured in the same units, and the energy must be wholly derived from some natural source of power, for the mechanism adds nothing to it. But the mechanism can be designed for *storing* or for *transforming* energy, and each of these operations is like a money transaction in business. It is worth while to look at the keeping of accounts.

Just as the merchant stores his money with the banker, so the engineer can lay up a store of energy, and can get it paid back at the moment when his business requires it. Such transactions are repeated very rapidly in the case of the fly-wheel, and nature charges no commission at all upon this short running account. But let us notice next that work (and therefore energy) is the product of *power* and *time*—the work *done* is the *effect* produced by a given power working steadily for a given time; and although mechanism cannot add to the stored energy, it enables us to draw out the store from nature's bank, at any rate that we please.

By means of clockwork, for example, we lay up in a few seconds of time a certain store of energy,

which is *slowly* paid back during the next twenty-four hours or the next eight days; and conversely we can employ an engine of small power to go on storing energy at leisure in the hydraulic accumulator, and then we can draw it off as *rapidly* as we please, exhausting the whole store, perhaps, in less than a minute, and so obtaining a very high power for a short interval of time—a very convenient arrangement for some purposes, such as the occasional working of swing-bridges. When such mechanism is employed for banking a store of energy, there is always something to pay on the transaction, so that we do not quite get the full value, in useful work, for the energy we have stored—but the engineer keeps the losses down as far as he can.

By various machines of another kind we can effect a regular and continuous *conversion* of power, so as to take out the value in one shape or another as may best suit the particular character of the work in hand. For "power" may be regarded as the product of force and speed, just as the money value of goods is the product of their quantity and their price. If, therefore, we have a steam engine of given power, we can make it apply a great motive force at slow speed (say, for the shearing of thick iron plates), or a much smaller force at a very high speed, as the

occasion may require. This is generally the function of such mechanism as wheels and axles, belts and pulleys, shafting and gearing; and they all consume some part of the original power in frictional work, transmitting only the remainder for the performance of "useful work." For every transaction of conversion or exchange nature keeps a strict account, and the engineer will do the same: the "energy expended" appears on one side of the account, and the "work done" is to be entered on the other side. There is always some loss on the exchange, owing to wasted work or lost energy, and the useful work is the net balance.

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against similar attractions and repulsions, generating a current in the armature by sweeping its wires through certain lines of force in the magnetic field.

If science has not explained the essential nature of magnetism and electricity, it has certainly ascertained with the utmost precision the laws that govern both of them, and if volts and ampères are intangible quantities, the measurements are none the less exact. The electrical engineer can do nothing without the aid of these principles, and although the fundamental laws are expressible in simple terms, they will be applied to a large number of complex problems in the design of every dynamo or electro-motor. Each separate member and every feature of the machine will be the subject of calculation; for its efficiency will depend upon the scientific selection of precisely correct dimensions for armatures, field-magnets, and their surrounding coils of copper wire. Under favourable working conditions the efficiency will be very high: the loss incurred on each exchange—from mechanical to electric and back to mechanical energy—need not be more than about 5 per cent., so that the electro-motor can deliver about 90 per cent. of the original power.

We have yet to consider the *source* of power, and its first development in the prime movers—the heat-engine and the water-wheel; for we cannot effect any

THE CUNARD COMPANY'S LATEST STEAMSHIP "CARONIA"

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transactions of *conversion* or *exchange* until we have something to convert. The electric locomotive is driven by the motor, but the motor derives its power from the transmitted current, the current from the generating dynamo, and the dynamo from the steam engine, while the steam engine takes its power from the heat of combustion, and *this* is the "source of power in nature," actuating all the machines in the series.

The engineer's first operation, therefore, is the conversion of heat into mechanical energy, and the science of "thermo-dynamics" deals with the laws of nature in regard to this conversion. When the Red Indian lights a fire by the heat of friction, the pieces of wood which he rubs together are really a dynamo-thermic machine transforming his muscular energy into heat; while the steam engine is a thermo-dynamic machine which effects a conversion of exactly opposite kind, transforming heat into mechanical energy (or work); and in either transaction nature pays at the same rate of exchange. It was exactly ascertained by Joule, and it is: One British unit of heat for 774 British units of work.[1]

[1] The British thermal unit is the amount of heat that is required in raising the temperature of one pound of water by one degree Fahrenheit: while the other unit is the amount of work done in lifting a weight of one pound through a height of one foot, *i.e.*, one foot-pound.

Here, perhaps, we should notice the historic fact that the steam engine was not suggested by the formulated law—the discovery of the law was rather suggested by the steam engine. James Watt had devised the engine for the distinct purpose of thermo-dynamic conversion, and it had been converting heat into work for at least forty years before Joule announced the "First Law of Thermo-dynamics," which states that heat can be converted into work, and lays down the exact rate of exchange.

The "First Law" does not mention that there are any limits to this process of conversion, and if there were none we might imagine that the engine was getting scanty payment in return for its expenditure of heat. This matter came to be explained, however, by the "Second Law," which shows that Nature pays honestly for all that she really takes, but she fixes certain limits to the process of conversion. She is willing, apparently, to begin at a point which may be as high as we like upon the scale of the thermometer, but when we get down to a certain point she stops business altogether, and will take no more heat at any price; and the result is that we are left with a certain stock of unconvertible heat upon our hands. This point is reached when we get down to the temperature of the surrounding objects in nature, and although we can go below it by

artificial processes, there is nothing to be gained by doing so.[1] It does not appear that Nature will transact the exchange on any other terms, and there is no sort of heat engine that escapes them. The way seems blocked in every direction, and the Second Law reveals the barrier. This law has been written in four different forms by Clausius, Rankine, Clark Maxwell, and Lord Kelvin, and in each case it stands like a notice-board inscribed with the words, "No thoroughfare."

In designing a heat engine it is always useful to know beforehand what *cannot* be done, as well as what *can;* but in looking at the limits to this conversion we must never lose sight of the enormous boon which Nature really confers in the exchange. The fact of primary importance to us is that she has *given us* the coal, and in the coal a store of energy so rich that we often fail to appreciate it. If it were required to lift a load of a hundred tons to the top of St. Paul's Cathedral, the work could be done, in spite of all the drawbacks, by burning less than six-pennyworth of coal. A single pound of coal, in the furnace of a steam engine, will do as much work as ten thousand pounds of water falling over Niagara.

[1] We have, in fact, to give back some power if we wish to produce any artificial cooling below climatic temperature, and on the whole this further transaction will be a losing one.

When used in a good condensing engine, the practical rate of exchange will be about one pound of coal for eleven or twelve hundred thousand units of work.

Apart from thermo-dynamics there has long been a theory of the steam engine relating to its visible mechanism and to the properties of steam, as ascertained mainly by the experiments of Regnault, and this theory must always be consulted by the practical engineer, who will work out his power-problems in units of pressure and volume. At the same time the thermo-dynamic methods, working by temperature and "entropy," will find useful applications in engineering, as they do also in chemistry and in physics. They have, perhaps, not suggested any important mechanical feature in the steam engine, but they point the way to a higher efficiency in the gas engine and the oil engine.

When George Stephenson was asked to account for the great power of his locomotive, he suggested that it was perhaps only restoring the work which had been done long ago by the sun's rays in laying up the atoms of carbon in the coal measures. And the power of the turbine or any other water-wheel must be traced back to the same ultimate source. The water of our rivers, as it descends to sea-level under the action of gravity, is only restoring the

work that was done upon it by the sun's rays when it was lifted to the mountain-tops against the same force of gravity, and deposited in the form of rain or snow.

As it falls through a height of about 140 ft. at Niagara, every pound of water restores 140 foot-pounds of that work, and the energy is expended in mechanical form so that no transformation is needed. The turbine will often exhibit an efficiency of 80 or 85 per cent., and for every pound of water will give us something like 110 or 120 foot-pounds of useful work, when the fall is as great as this vertical drop of 140 ft. at Niagara. In our own country we have no such great and lofty waterfalls. Not only is the discharge of our rivers very much smaller, but the work to be obtained from each pound of the water is at the same time less, being proportional, of course, to the smaller height of the fall.

To make the best use of such ordinary sources of water-power, the engineer will generally have to carry out large works of construction for the collection, storage, and conveyance of the water—such as are not required at Niagara.

In this matter of water-conveyance, whether for power-purposes or for the supply of towns, the engineer will be entirely guided by the scientific principles of hydraulics. All the numerous questions

relating to water-pressure and its effect upon his various structures will be determined by the absolute laws of hydrostatics, while the science of hydrodynamics will furnish the solution for many problems connected with the design of his turbines.

The flow of water in pipes, channels, and natural streams is, however, a subject which presents exceptional difficulties, and cannot as yet be treated by any mathematical deductions from hydrodynamics. Galileo found it harder to understand than any problem connected with the motion of the stars, and it still remains a question which can only be safely treated by experimental inquiry. But for many years past the hydraulicians of all civilised countries have united in prosecuting these experiments, and their co-ordinated results have been expressed in such mathematical form as to furnish a reliable basis for the practice of the hydraulic engineer. We have already seen that he continually makes use of such formulas in all his operations, fixing each detail in his designs by the aid of precise calculation.

Indeed, the same remark might be applied to almost every branch of engineering practice. In times that have gone by, many great works of construction were initiated and successfully carried out without much help or leading from science; but since that time science has become more practical, and practice has

become more scientific. It would be easy to mention a number of important problems which cannot be safely treated by any theory that stands written to-day in the text-books; and in all such matters the civil engineer must still rely upon the teaching of experience, and upon the instinctive leanings of what he would call common-sense. But scientific reasoning has been applied to the actual practical conditions which surround *most* of his problems, and its invaluable guidance has become indispensable to the modern engineer.

## CHAPTER VIII

### EDUCATION

THE British public is perhaps beginning to get tired of the educationist, for it is very difficult to follow all the ins and outs of his subject, although it has lately been so widely discussed. All the world, however, is agreed in recognising the importance of education.

In discussing educational systems or methods, the question whether they are well or ill adapted for their purposes cannot be rationally answered until we have clearly defined in each case what the purpose is. We are here especially concerned with the education of a civil engineer, and we must therefore carefully inquire —what are the objects to be served by an education in engineering, by what sort of study those objects are to be attained, and what facilities exist for the prosecution of such studies.

The answer that must now be given to these questions is, of course, very different from what it would have been fifty years ago. There is, perhaps, no reason why the teaching of Latin and Greek

should undergo any change from one generation to another; but in engineering the subject-matter that is teachable by any sort of process is not a constant quantity, for whether we regard it as a practical art or a progressive science, the subject grows with the widening experience of the engineer and with the constant advance of science.

The pioneers of civil engineering a hundred years ago had to lay the very foundations of the art. They were generally self-taught men, relying very much upon the independent use of reason, but studying every available source of scientific knowledge, and learning much from experience.

The Institution of Civil Engineers was founded in 1818 for the acquisition of such knowledge, but it did not undertake any educational work. Its objects were promoted by the reading and discussion of papers in the theatre of the institution, and by their publication in the Minutes of Proceedings.[1]

Through the earlier part of the nineteenth century it may be said that English people had scarcely heard of a special education in engineering. To many of them the engineer himself was almost a

[1] These volumes contain an extensive series of papers dealing very fully with the practice and the science of engineering, and they form a library of useful information for the engineer, relating to every branch of his profession.

mythical personage. His work appeared to be something entirely new and strange, not to say "uncanny," and by some people his methods were regarded as a new kind of trade secret—to be learned, perhaps, by personal acquaintance with the mysterious practitioner, and not in any other way.

At the same time, there were other people, especially, perhaps, in France and Germany, who looked at the matter very differently, and treated engineering as the mere application of known science. The student, after going through a regular course of physics and mathematics, was supposed to be fully equipped for the arduous duties of an engineer.

Thus the long warfare between the followers of "theory" and of "practice" began in the educational systems—in one school the pupil apprentice had picked up valuable knowledge by observation, and possibly without a glimmering of scientific method —while the academy student had learned his science from men who knew nothing whatever of engineering. When these students came to meet it was not likely that they could agree: each man had been satisfied with the half of an education, and there was scarcely anything in common between them.

From such disconnected methods of learning a great step in advance was made when, in 1840, the University of Glasgow adopted the specific subject

of civil engineering, for the first time, as an incorporated part of University training. The foundation of the Chair meant, at least, that science and engineering were not to be divorced, but brought together on the same plane. The great literary works of Professor Rankine remain with us to show how far he carried his investigations into new regions of practical inquiry, and they also show how he could use the problems of engineering as an exercise for those mental faculties whose cultivation is the worthy aim of all University work. For such purely educational objects the modern problems of engineering are perhaps better than the old problems of Euclid, because they are so much higher and so much deeper.

When Glasgow had set the example, it was followed by the University of Edinburgh, and also by Saint Andrews, which is the most ancient of the Scottish Universities, its original foundation dating from 1411 A.D. It is also probable that a Chair of Engineering will shortly be established at the University of Aberdeen.

For a long time Oxford and Cambridge would have nothing to do with the new subject, although its study is now carried forward at Cambridge at a level which befits the traditions of that home of mathematics. In London it was first taken up by

University College and King's College, which will now be merged in the University of London, and since that time Chairs of Engineering have been established in the University of Durham, in Mason's College, Birmingham (now the University of Birmingham), and in the colleges of Manchester, Liverpool, and Leeds, which are grouped under the Royal Charter of the Victoria University, and also in the University of Wales. In Ireland a School of Engineering has existed in Dublin University since 1842, and has been extended to the Queen's Colleges of Cork, Belfast, and Galway.

In all these Universities degrees are now conferred in Engineering, or in Civil Engineering, or in Science under the special divisional title of engineering. In Scotland engineering is treated as a Department in the Faculty of Science, while in some other Universities there is a separate Faculty of Engineering. At the same time the subject has come to form part of the teaching in a great many University Colleges, including those of Bristol, Nottingham, Sheffield, and Cardiff, as also in the Heriot Watt College at Edinburgh, and in the Glasgow and West of Scotland Technical College, while it forms the special subject of study in the Royal Indian Engineering College at Cooper's Hill.

During the latter half of the century the import-

SOUTH ELEVATION OF EDDYSTONE LIGHTHOUSE

*From an old engraving in Smeaton's "Narrative"*
*The structure was replaced by the new tower in 1882*

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ance of technical education in connection with all our industrial arts and manufactures began to be clearly recognised, and the Livery Companies of London combined for the purpose of developing a general scheme of technical instruction "adapted to the requirements of all classes of persons engaged in productive industry." The scheme provided for the foundation in London of a central institution for higher technical instruction; for the establishment of, or for assistance to, trade schools; for the conduct of examinations in technology; and for the subsidising of other institutions in London or in the provinces, having cognate objects. Thus the City and Guilds of London Institute was established in the year 1880, and it possesses two teaching establishments in London — the Central Institution at South Kensington, and the Technical College at Finsbury. Their main objects are "to point out the application of different branches of science to various manufacturing industries," and they include courses of instruction for engineers. The operations at the Finsbury College are divided into separate day and evening classes, and the latter are largely attended by students from fourteen to forty years of age, the great majority of them being employed during the day in workshops or in factories. The evening classes include such subjects as plumbing,

metal-work, carpentry and joinery, cabinet-making, builders' quantities, practical geometry, etc.

With similar objects in view, a very large number of technical schools and institutes have now been established all over the country, working with the assistance and under the regulations of the City and Guilds Institute, or of the Science and Art Department. They provide instruction in most of those branches of science which relate to engineering, and their classes are attended by large numbers of evening students who are engaged in their various occupations during the day.

Without extending the list any further, it is already evident that our educational facilities today are wide in extent, and in many of our cities the University and the Technical School are working side by side. We need not here attempt to look at the programme of work which is followed in each of these numerous institutions,[1] but we shall presently have to consider what objects are really to be attained by a college training, and some account of the students' usual line of work must therefore be given.

The University student will carry on his progressive studies in the four subjects of mathematics,

[1] In every case the syllabus of lectures and practical work will be set forth in detail in the published calendar, together with all regulations for preliminary examinations, final examinations and degrees or diplomas.

physics, chemistry, and engineering, taking, perhaps, three of them side by side in one session. Every day, therefore, he will pass from his own department to the adjacent lecture-halls and laboratories of two or three others. His course (for graduation) will generally extend over three academic years.

The courses in mathematics will comprise every branch of the subject that will usually be applied in engineering, at least as far as the integral calculus; and they may be supplemented by a special course in applied mathematics or applied mechanics.

In the Department of Physics or Natural Philosophy the lectures will deal with the subject of dynamics, and with the physical laws of sound, light, heat, magnetism, and electricity; while their visible phenomena will be illustrated and studied in a parallel course of practical physics by actual experiment and measurement in the laboratory. After these it will be open to the student to go on for a course of applied electricity (or electrical engineering) as an optional subject. It will obviously be chosen by the man who looks forward to the work of an electrical engineer, while the civil engineering student may substitute a course in geology, or he has the alternative of following a special course of systematic research in the laboratory.[1]

[1] These are the options allowed in the regulations of the Scottish Universities for a degree in engineering.

In the Department of Engineering the student's time will be divided between the lecture-hall, the drawing-office, the laboratory, and the field. The lectures will include several courses, or half-courses, theoretical and practical. The theory of engineering embraces so many questions that a full discussion of them would more than take up the whole of the student's time, but the winter lectures will deal with the problems which most frequently arise in the engineer's practice. At the same time the concurrent descriptive lectures will treat of the practical operations of the engineer, the actual materials of construction, their properties and their manufacture, the best methods of using them, and the purposes for which they are used: and some of these matters will be usefully illustrated by the parallel course of experimental work in the engineering laboratory.

The work that is carried on in such a laboratory is not of the same kind in all colleges, but it will perhaps suffice to speak briefly of the usual work at Dundee. Here the students will begin with the use of simple apparatus for determining the elasticity in wires of different metals, going on to some similar experiments upon bars of iron and steel by means of a micrometric extensometer. They will obtain a good experience in the use of the large testing machine for the ordinary testing of materials, and

will observe their behaviour under every kind of steady stress: while the advanced students will conduct experiments with the hydraulic fatigue press, discovering by these researches what is the actual strength (and the behaviour) of iron and steel when *fatigued* by the alternate imposition and removal of a given load repeated some hundreds of thousands of times.

The students will have time and opportunity for a few experiments in hydraulics, and they will all join in the making of power-measurements with the gas engine and the dynamos, and in carrying out a series of steam-trials with the experimental compound condensing (or non-condensing) engine.

For all this experimental work the students will often have the handling of machinery under supervision, but they do not use the laboratory as a workshop, although the machine tools are constantly in operation before them—planing, drilling, and turning the metal-work that is required in the laboratory.[1]

Passing on to the summer session, the work begins again (at Dundee) with a course of descriptive lectures, treating either of railway construction, or bridge-

[1] There is not much to be gained by a few hours of shop-work, even if the hours could be spared: and to obtain any thorough workshop training, such as would be required by the skilled artisan, would consume almost the whole time of the student, leaving practically none for the more proper objects of college study.

building, or harbour engineering, and a parallel course upon surveying. After this the whole class will take the field for about a fortnight of continuous work from morning to night — they will complete a survey, covering about a mile in length, followed by the running of levelled sections and the setting-out of railway curves by the theodolite. The detailed plans and sections will then be plotted in the drawing-office as the concluding work for that session.

When all this is carried out, the student's time is so well filled up that it is almost impossible to add another item to the programme for any one year.

The zealous educationist is apt to assume that his objects are to be attained by the multiplication of items, and by getting into his syllabus every cognate subject that can receive a distinctive title—but the solution of the educational problem is not so simple. The limitations of time, on the student's side, must be the first consideration, and it would be well to realise what is included in an ordinary day's work for the college student.

At nine a.m. he enters the Physical Hall and sits through a lecture of one hour, vigorously taking notes as the professor deals with electro-magnetism, or some problem in dynamics, or Fourier's Theory of Heat; then, without so much as a five-minute

interval, he crosses to the Mathematical Hall, where the lecturer begins at once upon the binomial theorem, or the differentiation of some function. At the end of this second lecture he passes straight into the drawing-office, and spends the next hour over some geometrical problem; and then goes at once for the third lecture, which may deal, perhaps, with the theory of continuous girders.

This brings him to one o'clock, and from two to five p.m. he will very likely be hard at work upon the footplate of a very hot engine, taking indicator diagrams at high speed. In the evening he will take his only opportunity of looking into the notes of his three morning lectures, and will then begin to work out his home exercises in each subject. By about ten p.m. he will have got through a very fair day's work.

Of course the work would soon become intolerable if it were not carried on with zest and interest, but these things are seldom lacking, and the classes work at a pressure which shows no drop during the session.

The extent of the ground that may be fairly covered in a course of three years may perhaps be illustrated by quoting, as an example, the present requirements at Edinburgh and at St. Andrews, for graduation in engineering.

In the course of not less than three academical years the candidate must attend at least the eleven courses of instruction in the following subjects :—

1. Mathematics, including Analytical Geometry and the Differential and Integral Calculus.
2. Natural Philosophy, including Higher Applied Mathematics.
3. Chemistry.
4. A course in the Physical Laboratory, or in the Chemical Laboratory, or of Practical Chemistry.
5, 6. Two courses in Practical Work in Drawing.
7, 8, 9. Three courses in Engineering, including Engineering, Laboratory Practice, and Field-work.
10. Natural Philosophy, involving Higher Mathematics.
11. One of the following :—
    (*a*) Engineering Laboratory Practice, Mechanical or Electrical (Special Course).
    (*b*) Electricity, Pure and Applied.
    (*c*) Geology and Mineralogy.

In this schedule a "course of instruction," in either subject, is generally held to mean one hundred lectures of an hour each, or two hundred hours of practical work. In practice, however, it is found necessary to extend the courses of drawing and

engineering far beyond the limits which are laid down in the ordinances as a minimum.

These regulations may perhaps serve as an illustration; but to answer the general question—How much should be attempted?—we have first to consider how much is possible for the student: and this is a finite quantity, although it may be distributed in different ways. If, however, we increase the superficial area, we shall by so much diminish the depth. The word "engineering" comprises so many different fields that we cannot cover them all, except by a sprinkling too thin to be of much solid value.

The engineer will carry on his studies through *all* the years of his life-practice, and *at the end* of them he will hardly profess to have a complete knowledge of every branch of civil, mechanical, and electrical engineering; and it is quite impossible for the youth, coming fresh from a Public School, to acquire in three years the training of a skilled artisan and the training required for three professions—a selection must be made.

For the mechanical engineer it may be necessary to go through all the manual work of the pattern-shop, foundry, smithy, and fitting shop; and it can best be done by the usual method of an apprenticeship.

In like manner, it is only in the office and in the

field that the civil engineer can obtain a good acquaintance with professional routine, and a practical experience in the execution of works.

Yet neither of these apprenticeships can take the place of a college training. The student will not find anyone to help him in the shop or in the office; nor will he find in either of them any opportunity for the prosecution of systematic study in the scientific principles of engineering. It seems inevitable, therefore, that the education of an engineer must be divided into two halves, because the whole cannot be taken in any one place; and the college work should obviously be directed to those objects for which it is specially adapted. This, at least, is the principle which is followed in most of our Universities and colleges, while the Technical Schools try to undertake something like an apprenticeship in a number of trades as well as a teaching in science, and in America the practical tuition appears to be carried out upon a great scale in all the details of specialised manufacture.

The governing idea is a different one in each of these three cases, and in each case the subdivision of work follows upon a different plan.

In the English Technical School some classes are devoted to the practical carpentering, plumbing, etc., and apart from these the teaching is subdivided into

a large number of different *branches of applied science.* Thus the science studies for an engineer must be taken up in eight or ten different class-rooms under as many different teachers, and in accordance with the regulations of the City and Guilds Institute. Some such division of labour is probably necessary in dealing with the very large number of students in the evening classes:[1] but it is attended with disadvantages which are fully recognised by the teachers. The study is discontinuous, and there is an inevitable repetition of subject-matter, involving a waste of time which the evening student can ill afford.[2]

On the other hand, the teaching of engineering in an English University is subdivided only between the different *professions* of civil, mechanical, and electrical engineering. The student who is preparing for either profession will study the whole of his engineering under one professor, who is perfectly free to arrange his courses so that the student

[1] There are, for example, more than 2,000 evening students in the Engineering Department of the Birmingham Municipal Technical School.

[2] Such propositions, for example, as those relating to the composition and resolution of forces must be taught a great many times by different teachers—first in "Theoretical Mechanics," then perhaps in "Graphic Statics," then again in "Building Construction," in "Mechanical Engineering," in "Machine Design," and once more under the heading of "Steam."

shall follow a continuous and progressive line of thought and study. But in some American colleges there is again a different subdivision as between certain *specialties of engineering work* or manufacture. Thus in one department the subject-matter is confined to the locomotive engine, in another to the building of railway carriages and goods waggons, and so on through a long list; so that in one college there are as many as twenty professors of engineering and more than forty assistant lecturers and demonstrators. These sectional exercises are carried out in very thorough and practical fashion, after a general engineering education; but the entire course extends over a period of five years, and in that time it can scarcely include more than one or two specialties.

It is impossible that any one educational system can be the best for every individual whose occupation comes under the all-inclusive title of "engineering," if his training is to be any preparation for his work in life.

For a large number of evening students, it is almost certain that engineering will mean chiefly the work of a skilled artisan at the bench or the turning-lathe; and a training in the modern methods of accurate workmanship would perhaps be more valuable than anything else.

DISTANT VIEW OF THE NILE DAM AT ASSOUAN

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For a certain number of mechanical and electrical engineers, the same word means a *trade* or *manufacture*, which will be carried on for the making of money profits; and for them a "commercial education" will seem to offer advantages of a tangible and eminently practical kind.

For the man of academic pursuits, it means a *science* branching off into numerous subsections, whose titles are to be read in the syllabus of the educationist.

But for men of progress, and for every civil engineer, it means neither a handicraft, nor a trade, nor only a science, but includes something quite different from either of them. If we put together all the subsections of applied science as they appear in the most exhaustive syllabus, they do not make up a sum total which can properly be called engineering; there is one item left out of the syllabus, and it is a very important one. The essential nature of engineering is best illustrated by the record of its achievements, and these pages have shown that it does not consist merely in the application of science, but rather in the application of *reason*, which is a different matter.

Evidently, therefore, we are driven back to the question which was raised at the beginning of the chapter: What is the particular object that we hope

to attain by any proposed course of education? The soil is fertile enough, but in this, as in other matters, the universal law holds good that men will always reap that which they sow, and not any other kind of fruit; and the law must apply to educationist, teacher, and student.

Thus if we adopt the system of "payment by results," it is almost certain that we shall obtain the results which are paid for—*i.e.* the passing of a large percentage of students through the test-examinations; but the value of that result is another question. Again, if the teacher of an evening class is compelled to work under this system, he has no option but to set before him the same "results" as the object of his endeavours; and he will safely accomplish that object if he follows the well-tried method of storing the student's *memory;* but it cannot be expected that this "cramming" process (as it is called) will result in the cultivation of any *other* intellectual faculty, and the mere exercise of memory is absolutely valueless in the work of the civil engineer.[1]

[1] It is already pretty well known that the faults of the "cramming" system are not only on the negative side. It does nothing for the development of the best intellectual faculties, but it may often do a great deal to stunt or entirely destroy their natural growth. How strongly it represses the exercise of individual thought may be seen by a glance at some of the advanced text-books "approved" for use under this system. The system of "payment by results" has lately been abolished in the evening Technical Schools in Scotland.

For the business of reproducing machinery, it may perhaps be enough if the student can apply the rules and formulas which he has learned to use; but we have seen that the designs of the civil engineer must always involve the exercise of independent thought and of that creative faculty which finds for itself the means that are best adapted to its end. This is not the natural fruit of any commercial instinct, and is therefore not likely to be developed in the mind of the student who aims only at the future reaping of mercantile profits.

Perhaps these faculties cannot be imparted by any mechanical process of mere instruction—whether in art or in engineering. But they are the gift of nature—the born heritage of the Anglo-Saxon race; and they will grow if they are cultivated for their own sake—for it is Nature's own law that men shall reap what they sow.

## CHAPTER IX

### PAST, PRESENT, AND FUTURE

LOOKING back over the little bit of history recorded in these pages, we cannot help seeing how the conditions of modern life have been affected by the changes which engineering has wrought; but it is equally true that engineering itself has been undergoing a ceaseless change. If the art and the literature of the Victorian Age have been profoundly affected by surrounding influences, the same thing is true of engineering. Its relations with the outside world of men are not at all what they used to be—perhaps its objects are not quite the same, for they have been influenced by the requirements of modern life; its methods are very different from what they were in past times; its resources are much greater; and certainly our knowledge of nature is very much wider than it ever has been before.

In the meantime, however, there has been no essential change in the character of the engineer's warfare with Nature, or in Nature's dealings with him—*she* has made no change in her laws; whatever

else may have altered, they, at all events, remain what they always were.

Since the date at which this story begins, the profession of civil engineering has come to occupy a recognised position in the community. The engineer is not now regarded as an excentric wanderer without a definable vocation in life; the world has altered its estimate of him and of his business.

At first he had an uphill fight before him; nobody would believe in the practicability of his projects; people could see very clearly the enormous difficulties that lay in the way, and only a few could estimate the sufficiency of his means for overcoming them, or could appreciate beforehand the public benefits that were likely to accrue from his projected works. Many doubted, and could only believe when they saw.

But the early engineers had fully estimated all the difficulties; their plans had not been laid without a careful reckoning of ways and means, and they knew that the great sources of power in nature were adequate for their purposes. Their works of construction were carried through with unfailing success, and soon began to demonstrate their usefulness. The successive "triumphs" of engineering became the theme for general congratulations, and after

a few years the doubts had disappeared, and had given place to an unbounded confidence.

This change in the mental attitude of the public has, of course, greatly altered the prospects of engineering enterprise—its progress to-day is certainly not checked by any lack of public confidence. At the same time it has imposed upon the engineer the duty of making his reckonings with nature more carefully than ever.

At one time the pendulum swung so far in the opposite direction that many people lost sight of the natural difficulties altogether, refused to recognise their existence, and almost came to believe that *nothing* could be impossible to the *magic* of engineering science. A single incident may suffice to illustrate the change.

We may remember, for example, that when it was first proposed to cut a ship canal through the Isthmus of Suez, the project was regarded by most people as bold and hazardous in the extreme, for the natural difficulties were obvious and were thought to be insuperable. But in due time the canal was completed, and a few years afterwards the Panama Canal was enthusiastically commenced without the slightest misgiving. The difficulties that really surrounded that undertaking might perhaps have been ascertained beforehand by a patient expenditure

of time and study and some expenditure of money, but their magnitude was only found out when the operations were far advanced. The works had to be abandoned when something like £90,000,000 of capital had been expended, and they have remained in an unfinished condition from that time to the present day.

The student will be wise to remember that the civil engineer has still to conduct the same old warfare with Nature, and that her forces are not in any way diminished. It is true that the resources on his side have been greatly augmented, but the magnitude of his task has increased at the same time and in like proportion. He will only court defeat if he pretends to under-rate the forces of the enemy; and he needs to-day, just as much as ever, all the foresight and tactical skill that he can bring to bear upon his task.

We may go on to observe that the engineer's resources have been extended in many directions, and first that some of his operations have been greatly assisted by the introduction of new materials of construction and by successive improvements in their manufacture, so that in some kinds of work his methods of procedure have been almost revolutionised in consequence.

This has been especially noticeable in the employ-

ment of steel and of Portland cement concrete in works of construction. In each case the material was at first regarded with some degree of mistrust, owing to the uncertain quality of the product or its uncertain behaviour under subsequent treatment; but with later improvements in the manufacture these troubles disappeared, and the engineer has placed concrete and mild steel among the most reliable of all his materials of construction.

The use of cement concrete has enabled the engineer to undertake many submarine operations which had not been possible without it. The older methods of dealing with such difficulties have, therefore, been set aside, and the harbour engineer generally designs his breakwaters and his submarine foundations with the view of employing this material in one form or another, and taking advantage of the facilities which it affords. It has come to be freely used also in the lining of tunnels, the construction of dock-walls, and the building of many other lithic structures.

For the first half of the nineteenth century the manufacture of Portland cement was almost entirely confined to the valleys of the Thames and the Medway, and the material seems to have got its name from the London builders, who used it merely for covering their brick walls with a stucco resembling

Portland stone. The London "Portland cement" was at that time well known in most Continental countries, and was imported into Germany in preference to any other kind of building cement.

It is quite certain that the annual production of Portland cement must have increased enormously since it began to be used by engineers for the making of concrete in large quantities, and in all probability the demand will increase still further. Its manufacture was soon taken up in the Lias districts of the Midland Counties, and has been extended to many other parts of the United Kingdom. For some years past it has been very successfully carried on in Germany, where it has been studied with the scientific thoroughness which distinguishes the people of that country, and the German maker of Portland cement is now a formidable competitor in the English market.

In discussing the modern methods of steel-making, we have already noticed some of the results which have followed upon the production of mild steel and its use in the place of wrought-iron. Its greater strength has enabled the boiler-maker to meet the requirements of high pressure; and with the higher boiler pressure the efficiency of the steam engine has been greatly increased, with a corresponding reduction in the consumption of coal per indicated

horse-power. In the same way its greater strength, as compared with that of wrought-iron, has been of immense service to the designer of long-span bridges, in promoting that economy of material which forms an essential condition of his problem.

For either of these two purposes, as well as for shipbuilding, it is necessary that the material should be not only strong but also tough and ductile, and a combination of strength and ductility in the same material is not easily obtained. Various grades of steel are now produced in the form of bars and plates, but the strongest ones are deficient in toughness, and are generally ruled out by the specifications of bridge engineers and of all shipbuilders. There must always be a limit to the width of span that can be crossed by the bridge-builder, and the limit is fixed by the ratio between the *strength* and the *weight* of the building material. The limit is practically fixed to-day by the ratio as we find it in the tougher grades of steel, but it may possibly be extended in the future by the use of some alloys combining ductility and toughness with a higher grade of strength.[1] The durability of wrought-iron and steel is still limited by the somewhat rapid oxidation which takes effect in both materials.

[1] The metal aluminium has often been suggested, but has not been used in bridge-construction, owing partly to its costliness, but still more to the difficulty of working it.

In quite recent years a combination of Portland cement concrete, with an internal strengthening of steel rods, has introduced a new material of construction under the name of ferro-concrete. It has been successfully used, in the place of timber, for bridges of moderate span, in the form of beams and flooring; and also in arches, braced landing-stages, and various kinds of pile-work, the piles being driven in the ordinary way. Its strength must certainly depend upon the internal arrangement of the steel rods, which are entirely embedded in the concrete, and are therefore invisible; but the durability of the material is a great point in favour of its extended use in the future.

It may perhaps be worth noticing that whenever timber has been replaced by a new building material the designer seems to have been constrained, by force of tradition or by association of ideas, to reproduce the familiar features of his earlier work. In the very best period of Greek architecture the features of a more ancient style of timber construction were repeated in stone upon the portico of every temple; and when the classic styles were revived in later centuries the same familiar features were repeated in all sorts of materials—in the stucco of London house-fronts, the mahogany of sideboards, and the painted decorations of churches.

They are now reproduced once more in ferro-concrete; but it is still more remarkable that the naval architect should have so closely followed the skeleton framework of the old "wooden walls," that keel and kelson and ribs and stringers are all made to reappear in the modern ship of iron or steel.

On the other hand, the builder of steel bridges has gone right away from the old architectural models, and his designs have taken such widely different shapes that they appear to be new creations rather than the mere development of pre-existing types. It is hardly possible, however, that he could have cut himself so completely adrift from the old ideas, if it had not been for the new ideas which were suggested to him by the study of mechanical theory. The theory of construction is itself one of the modern resources of civil engineering, and in this matter of bridge-design it has rendered its greatest service by revealing the principal mechanical functions of the structure, and suggesting the form that it might take for the best fulfilment of some of its various purposes.

In America the construction of steel girders upon certain standard patterns has been carried on by many bridge-building firms as an ordinary trade, and the manufacture of such "spans" has been cheapened by the use of special machinery for reproducing all

THE BARTON SWING BRIDGE CARRYING BRINDLEY'S OLD CANAL OVER THE NEW MANCHESTER SHIP CANAL

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the structural details in large quantities. The repeated production of such stereotyped forms is one of the results that have followed from the competitive system under which so many bridges have been built in America, and the system has been attended with some other results which are worthy of notice.

The competition in many cases was governed wholly by the question of cheapness, for the municipalities in some of the States were compelled by law to accept the lowest tender in every case. Under this system it was required that the structure should comply with the rules of a specification which dealt mainly with the testing of materials and the detailed calculation of stresses, but made no stipulation as to the form or construction of the girders; so that the design was left to find its most economical shape under the stress of competition, and with such safeguards as might be afforded by the figures of the calculation.

The system has borne its natural fruit in the development of a very economical style of bridge-construction for spans of a certain limited width; but the construction has never satisfied the practical judgment of English engineers. They have entertained an instinctive objection to the extreme slenderness of its proportions, adhering in their own practice

to a more solid style of construction which has never failed to ensure stability; and their objections have certainly found some justification in the large number of bridge failures that have happened in America, where the long list of accidents is such as no other country has experienced.

The mischievous tendency of the competitive system has been recognised by American engineers more clearly than by anyone else, and they have spent the utmost ingenuity in trying to counteract it by a more rigid application of the theory of stresses and by raising the standard of the stipulated conditions. But the fault lies probably in the system itself—it enlists all the forces of human ingenuity on the side of economy, while it leaves the safety of the bridge to be guaranteed by a set of written rules, and the rules cannot hold their own in such an unequal conflict.

In our own country the bridge-designer has built up the same mathematical theory of stresses, and has relied upon the information which it conveys; but while he has used it as an indispensable ally in his warfare with nature, he has not trusted that his warfare could be finished by the mere working out of an arithmetical sum. His study of the whole problem has convinced him that there is something else to be borne in mind, and his designs have always

been guided by certain considerations of a practical kind which are not mentioned in the theory of text-books nor in the rules of the competition.

The dissatisfaction of American engineers has not prevented the spread of the competitive system; and at the present time British and American firms are often found as competitors for the execution of foreign or colonial contracts. But the British designer is heavily handicapped by his own instinctive preference for solidity of construction, and he is generally left far behind in the race for cheapness.

It is likely enough that the result might be different if both contractors were tendering for the same design; but the Englishman could scarcely hope to secure many contracts under the system of competitive design unless the rules were so drawn as to give effect to the unexpressed practical ideas which influence his own mind. A complete and rational theory of safe construction, if it should ever come to be written, would have to include the treatment of many questions beyond the mere calculation of stresses and strengths, or the application of the Column Formula, or the so-called Factor of Safety:[1]

[1] The text-books have not yet defined precisely all that is, or that should be, comprised under the word "safety." If it were merely a question of stress and strength under given conditions of loading, a house of cards must be described as a very "safe" structure in calm weather. But the word must obviously include a great deal more, and must have a reference to *every* possible kind of failure.

it would have to give expression to those undefined considerations which influence the mind of the practical man.

The modern resources of the civil engineer include a great many ingenious appliances and processes which were unknown in earlier times. Some of these inventions have been devised with the special object of combating the natural difficulties which surround his operations; and besides these, he can reckon among his engines of warfare a great host of mechanical and electrical appliances — excavating, dredging, pumping, mining, and hoisting machinery, diving apparatus, and every modern application of motive power for the transport of materials, or for their treatment in the workshop or in the field.

The future progress of the civil engineer must always depend upon the "sources of power in nature," not only because he uses them for his own purposes, but because his works of construction are themselves bound up with the application of power for the "use and convenience of man." Harbours and waterways are made for navigation, and railways for the locomotive.

It is worth noticing, therefore, that the available sources of natural power are practically the same to-day as they have been from the beginning of this story. All the machinery that is used at the present

time by the civil, the mechanical, or the electrical engineer, for the performance of every kind of heavy work, derives its whole power either from the rainfall or from the combustion of fuel: and no other natural source of power has yet made its appearance within the region of practical engineering.

In this matter the anticipations of the public mind have often gone far beyond the more sober reckonings of the engineer. Many people have insisted upon endowing him, in spite of all his protestations, with the miraculous power of creating energy; the newspaper writers have described him as a sort of Prospero; and if he has not already achieved the impossible, they are convinced that he is now on the verge of accomplishing it.

These popular expectations have taken various shapes from time to time, as they have been suggested by the latest discoveries. Machinery seemed to move by magic, and it was at one time expected that perpetual motion would be obtained by some new arrangement of dead mechanism, such as the water-wheel-and-pump combination, or some later invention of the same kind; while the Keeley motor was apparently intended to meet the same popular demand. In more recent times it was hoped that the artificial production of liquid air would furnish us with an unlimited supply of energy, which would

make us independent of the old sources of power; but to-day this has given place to an expectation that the same thing will be accomplished by electricity; and we may often read a magazine article which describes electrical machinery as though it worked by some vitality of its own.

We have already seen, however, that all these appliances, whether mechanical or electrical, are used only as instruments for the transformation or the transmission of energy, and that they add nothing to the power of the prime mover, which is either a water-wheel or a heat engine.[1] These practical facts have long been patent to British engineers, who have often raised their voices to protest against the extravagant consumption of coal and its lavish exportation from our shores; but it may be doubted whether these sermons have yet produced any wide conviction as to the great value of this gift of nature to the British people. The annual consumption of coal for domestic purposes has, of course, greatly increased: the employment of powerful steam engines upon electric tramways has created a new demand: outward-bound vessels without a return freight are filled with coal for ballast; and many hundreds or thousands of tons

[1] Of course, it may be a windmill, or it may be a machine worked by the muscular power of men or animals; but they are hardly worth reckoning in the work of the world.

are burnt daily for the sake of an extra knot of speed in our luxurious Atlantic liners.

Passing on from this outlook, we may notice that the methods of civil engineering have been greatly changed by the continual progress of science. The engineer has taken up the discoveries of the physicist, and has turned them to the use and convenience of man; and this has been especially noticeable in electrical engineering. The discovery of the Hertz waves was the necessary forerunner of wireless telegraphy, but might have remained as the discovery of a scientist, and nothing more, if it had not been followed up by an application which demanded the engineering instincts of a man of different mould.

In the course of some previous chapters we have seen how the practice of engineers, in every branch of their profession, has been affected by the advance of applied science. Their methods have become more strictly rational, and very much more precise. In working out his designs, the engineer must now go into close calculations at almost every step, and will scarcely venture to rely upon his own instinctive judgment without their aid. This, no doubt, is a distinct gain in one direction, although it may be a loss in some others. It is a gain in point of certainty, for it avoids the possibility of quantitative mistakes, and it is an obvious gain in point

of economy. But the design may lose something in other directions, which are not so easy to define. The artist feels that he is suffering a loss of the same kind when he passes from the congenial habit of freehand sketching and places himself under the bondage of rules and studied formulas: while his mind is occupied with *them* it is less fruitful of ideas; and if the engineering draughtsman is constantly referring to scientific calculation, he may sometimes cramp those better faculties of original thought which must be exercised upon his wider problem of adapting means to an end.

For the mechanical or the electrical engineer whose immediate work may lie in the reproduction of machinery, the balance of advantage may be on the side of precise calculation; but the civil engineer must never lose sight of the ever-changing conditions of his wide problems, or allow his view of them to be obscured by a concentrated attention to the mere calculation of dimensions or quantities.

It is easily to be seen, also, that these changes are reflected in the architecture of civil engineering; for every kind of architecture is expressive, and shows forth the spirit of the age, as well as the mind of the designer.

The engineer has never cared to load his structures with ornament, but he has sometimes achieved the

happiest æsthetic results with the greatest simplicity of structural outline. A refined fitness of form to structural purpose is an element of beauty which appeals to everyone in the old Greek architecture, and the same element is conspicuous in the charming outlines of Smeaton's old Eddystone Lighthouse; while many of our great masonry bridges may fairly be ranked as fine architectural designs.

If the same thing cannot be said of our later bridges in iron and steel, yet they also are expressive in their own way—some of them have displayed a boldness of conception which belongs wholly to modern times, while many others express nothing so clearly as the inexorable necessity to build cheaply, and the guiding influence of applied science. A beautiful style of architecture in steel is perhaps one of the things which the future may have in store for us.

Amongst all these changes it has not been easy for engineering to preserve the breadth and simplicity of its original aims. The requirements of modern life include a great many things that were not dreamed of fifty years ago; and the old programme which was directed to the "use and convenience of man" is hardly enough for the demands of this age of luxury.

At the same time, the growing activity of commerce and the constant struggle of trade competition,

pressing always towards the realisation of immediate profits, have produced their inevitable effects upon engineering. The terms of a recent American definition have described the engineer as "the man who can do for 99 cents what anyone can do for 100"; and it is obvious that the author of this saying must have wholly lost sight of those wider possibilities which come within the vision of the civil engineer.

We must, however, recognise the fact that mechanical and electrical engineering have now become important commercial industries, in whose prosperity we are all interested; and under the pressure of international competition, it is perhaps inevitable that their development will continue to be greatly influenced by considerations of a purely commercial kind.

In conclusion, we may surely say that the future of engineering is still full of promise—for the world, and also for the engineering profession. We have still to provide for the plain uses and conveniences of man over a great part of the semi-civilised earth; and at home there are still a great many human needs which have not yet engaged the attention of engineers, and which might be fulfilled by the great sources of power in nature. The useful occupations and the salaried appointments which are already open to engineers have been referred to in a previous

chapter, and they are likely to be extended as time goes on—and the labourer in this field is worthy of his hire.

The future progress of engineering must certainly depend in great measure upon the education of the present time. This fact has already been clearly perceived by men of business, not only in this country, but for a long time past in Germany and in America; and everywhere men are looking to education as a powerful factor in the future rivalry for commercial supremacy.

But the educationist may still be tempted to cling to the old idea that engineering must be either a trade, or a science, or a combination of the two, for he does not easily see where anything else can come into the question. He has already done everything that he can think of for the diffusion of scientific knowledge, and we now hear much of a coming commercial education.

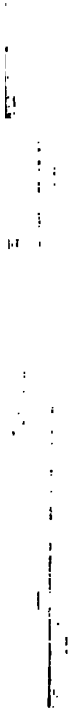
We should do well, however, to remember that the great fruits of engineering in the past have not been reaped from the sowing of these two seeds. When James Watt had to mend the old model of Newcomen's engine, he certainly did not set about that task upon business principles; and if he had been guided by a sound commercial education, it is not likely that he would have spent his years in the per-

fecting of a machine for which there was no demand in the market.

At every step in the history of early engineering we can see quite clearly that no progress would have been made unless men like James Watt and his successors had been able to look beyond the teachings of contemporaneous commerce, and to act independently of them. It was only in this way that the British people took the lead in the world of engineering, and kept it through the nineteenth century; and although a commercial education may enable them in the future to press hard *after* their German and American rivals, it cannot enable them to maintain the lead.

And the reason of all this is not far to seek. The engineer cannot achieve the true objects of his mission in the world without the cultivation of certain mental faculties which lie outside the natural habits of thought in business or in science. The man of science looks at things *as they are*, and tries to discover the truth about them; while the man of business must always take things as he finds them, and try to make the best of them. But the civil engineer cannot look at *things* in this way—his work has always lain in the designing of things that are not.

STEEL ARCHED BRIDGE OVER THE NORTH SEA SHIP CANAL



## CHAPTER X

### THE INSTITUTION OF CIVIL ENGINEERS

THE history of this institution has been coeval with the life of engineering in this country as a civil profession. It was first established, with a very small roll of members, on the 2nd of January, 1818, and was incorporated by Royal Charter on the 3rd of June, 1828, "for the general advancement of mechanical science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a civil engineer."

In later times it has become the parent of several societies and institutions which have been devoted to particular branches of the profession—mechanical, electrical, municipal, and some others; but it still remains as the chief representative of the whole family, and finds room within itself for the development of every branch.

The terms of its Charter, whose wide significance has been illustrated in the first chapters of this story, may be regarded as the true charter of the whole profession.

The corporate membership of the institution is now divided into four classes, viz. :—

1. Members.
2. Associate Members.
3. Associates, elected prior to 2nd December, 1878.
4. Honorary Members.

At the same time, provision is made for two other classes, which are attached to the institution, viz. :—

5. Associates elected later than 1878.
6. Students.

And among the students there are local associations at Manchester, Glasgow, Birmingham, Newcastle, and in Yorkshire.

The roll of the institution on the 1st of October, 1902, included the following numbers :—

| | |
|---|---|
| Honorary Members . . | 18 |
| Members . . . | 2,101 |
| Associate Members . . | 4,020 |
| Associates . . . | 293 |
| Students . . . | 896 |
| Total . . . | 7,328 |

The qualifications for election into each class are defined by the by-laws and regulations as follows :—

1. Every Candidate for election or transfer into the class of Members shall be more than thirty years

of age, and shall come within one of the following conditions :—

He shall have been regularly educated as a Civil Engineer, shall have had subsequent employment for at least five years, and shall be actually engaged at the time of his application for election, in responsible situations as Resident Engineer, or otherwise, in some of the branches defined by the Charter as constituting the profession of a Civil Engineer ; or,

He shall have practised on his own account in the profession of a Civil Engineer for at least five years, and shall have acquired a considerable degree of eminence in the same.

2. Every Candidate for election into the class of Associate Members shall be more than twenty-five years of age.

(*a*) He shall have been regularly educated as a Civil Engineer, shall have passed such examination or examinations as are appointed or are recognised by the Council, and shall be actually engaged at the time of his application for election, in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter ; or,

(*b*) He shall satisfy the Council that he has had a sufficient training, that he has been engaged for at

least five years, and that he is actually engaged at the time of his application for election, in the design or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter, and shall furnish a satisfactory Thesis or Paper on a professional subject; or,

(*c*) He shall, whilst complying with either of the foregoing conditions as to training and occupation as set forth in the paragraphs (*a*) and (*b*), afford satisfactory proof to the Council of his fitness for election without either examination or the submission of a Thesis or Paper.

3. The Associates entitled to the privileges of Corporate Membership are defined as comprising all those who were on the Register as Associates on the 2nd December, 1878.

4. Honorary Members shall be either distinguished individuals, who from their position are enabled to render assistance in the prosecution of public works, or persons eminent for science and experience in pursuits connected with the profession of a Civil Engineer, but who are not engaged in the practice of that profession in the United Kingdom or its dependencies.

5. "Associates" are defined as persons who are not Civil Engineers by profession, but whose pursuits

constitute branches of Engineering, or who by their connection with Science or the Arts, or otherwise, are qualified to concur with Civil Engineers in the advancement of professional knowledge.

6. "Students" are defined as persons not under eighteen years of age, who are, or have been, pupils of Corporate Members of the Institution, who have complied with the regulations of Section IV. of the By-laws, and who have the object or intention of becoming engaged in the design or in the construction of such works as are comprised within the profession of a Civil Engineer; and such persons may continue Students until they attain the age of twenty-six years.

For the sake of the non-professional reader, it should perhaps be explained that the ordinary meetings of the institution are held for the reading and discussion of papers on one evening of the week, and that no work is done in the institution by members or students. There are no students receiving instruction in the institution, and no kind of educational work is undertaken by that body. But young men who are studying the profession elsewhere, as pupils or assistants, may in this way join the institution while they are yet students; and it is now the common practice of young engineers thus to obtain their first induction to the institution as

"students," with the view of passing on to associate membership when they become qualified for that further step.

The regulations prescribe that the candidate who seeks admission as a student must have passed an examination which is nearly parallel with the matriculation examination in the University of London or the preliminary examination for entrance into either of the Scottish Universities; and the candidate is not required to take an examination if he has passed either of the following:—

University of London.—Matriculation exam.

Victoria University.—Preliminary exam., provided that Mechanics and one other Science subject is included.

University of St. Andrews.—Preliminary exam. in Science.

University of Glasgow. — Preliminary exam. in Science.

University of Aberdeen.—Preliminary exam. in Science.

University of Edinburgh.—Preliminary exam. in Science.

University of Dublin.—General exam. at end of Senior Freshman year.

University of Wales.—Matriculation exam., provided that additional Mathematics and either Dynamics or Chemistry be covered by the Certificate.

King's College, London.—Exam. for the College Matriculation Certificate in Engineering.

University College, London.—Matriculation exam. (Engineering Dept.)

Royal Indian Engineering College, Cooper's Hill. —Entrance exam.

City and Guilds of London Central Technical College.—Matriculation exam.

University College, Bristol.—Preliminary exam. (Engineering Dept.)

Scotch Education Department.—The Leaving Certificate, provided that Mathematics on the Higher Grade and a Science subject be included.

The candidate is exempted from examination if he is already a graduate of any University in the British Empire, and also if he has obtained either of the following certificates, provided that the requisite subjects in the Institution Studentship Examination be covered thereby, viz :—

Oxford Local Examinations.—A Senior Certificate.

Cambridge Local Examinations.—A Senior Certificate.

Oxford and Cambridge Schools Examination Board.—A Higher Certificate.

Central Welsh Board.—A Senior or an Honours Certificate.

University of Adelaide.—Senior Public exam.

University of Tasmania.—Senior Public exam.

The examination prescribed by the institution for students comprises the following subjects:—

1. English (one paper).
2. Mathematics (two papers).
3. Two subjects to be selected by the candidate from the following ten: a language is not compulsory, but in any case not more than one language may be taken:

   (i.) Latin; (ii.) Greek; (iii.) French; (iv.) German; (v.) Italian; (vi.) Spanish; (vii.) Elementary Mechanics of solids and fluids; (viii.) Elementary Physics; (ix.) Elementary Chemistry; (x.) Geometrical and Freehand Drawing.

When the candidate is elected as student, he does not yet possess the privileges of corporate membership, but he is entitled to attend the ordinary meetings of the Institution in Westminster, without having a vote in the election of president or members of Council; and he has the use of the library, and receives a copy of the minutes of proceedings. The students also hold their own meetings for the reading and discussion of papers.

In passing on to the grade of associate membership, it will be seen that three avenues are open to the candidate, and the first includes an examination in general knowledge and in engineering science.

This examination for associate members is nearly parallel to the final degree exams. in engineering in the University of London or either of the Scottish Universities; and the candidate is exempted from taking any part of it if he already holds either of the following University degrees:—

University of London.—B.Sc. (Engineering).
University of Cambridge.—B.A. (Mechanical Science Tripos).
University of St. Andrews.—B.Sc. (Engineering).
University of Glasgow.—B.Sc. (Engineering).
University of Edinburgh.—B.Sc. (Engineering).
Victoria University.—B.Sc., with Honours in Engineering.
University of Dublin.—B.A.I.
Royal University of Ireland.—B.E. and M.S.
University of Wales: B.Sc. (Engineering), provided that Mathematics be passed at the final examination for the degree.
McGill University, Montreal.—B.Sc. (in the Department of Civil, Mechanical, Electrical, or Mining Engineering), provided that Geography and either Physics or Chemistry be passed at the Matriculation Exam.

These degrees are recognised by the Council as proving a sufficient standard of attainment in the requisite subjects.

The examinations, which are prescribed by the

Council in other cases, for an associate member are divided into two parts as follows:—

### Part I.

### GENERAL KNOWLEDGE

Candidates will be required to prove their knowledge of the English language and their attainments in general knowledge by writing an essay of about a thousand words upon a set subject. Each candidate will be allowed to select one out of several subjects, including English history and literature, prescribed by the examiners.

Persons who are, or who have been, students of the Institution, or who produce such qualifications as would, under the existing regulations, exempt them from the examination applying to the admission of students, will not be required to pass Part I. of this examination.

### Part II.

### SCIENTIFIC KNOWLEDGE

#### Section A

1. Applied Mechanics.
2. Strength and Elasticity of Materials.
3. Either (*a*) Theory of Structures, or
   (*b*) Theory of Electricity and Magnetism.

## SECTION B

Two of the following nine subjects, taking not more than one from either group:—

*Group I.*—Geodesy. Theory of Heat Engines. Metallurgy.

*Group II.*—Hydraulics. Theory of Machines. Thermo- and Electro-Chemistry.

*Group III.*—Geology and Mineralogy. Stability and Resistance of Ships. Applications of Electricity.

The range of the examinations in the several subjects is indicated by a detailed syllabus, which is issued by the Council.

The Institution of Civil Engineers has now reached its seventy-sixth year, dating from its incorporation by Royal Charter; and the one hundred and fifty volumes of its transactions are perhaps the most valuable part of an engineer's library.

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